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MONTANA ENERGY CONSERVATION PLAN

Working Paper No. 9

BIOMASS CONVERSION

A Report to the
Montana Energy Advisory Council

Prepared for
The Montana Energy and MHD Research and Development Institute, Inc.
Butte, Montana

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9.0 BIOMASS

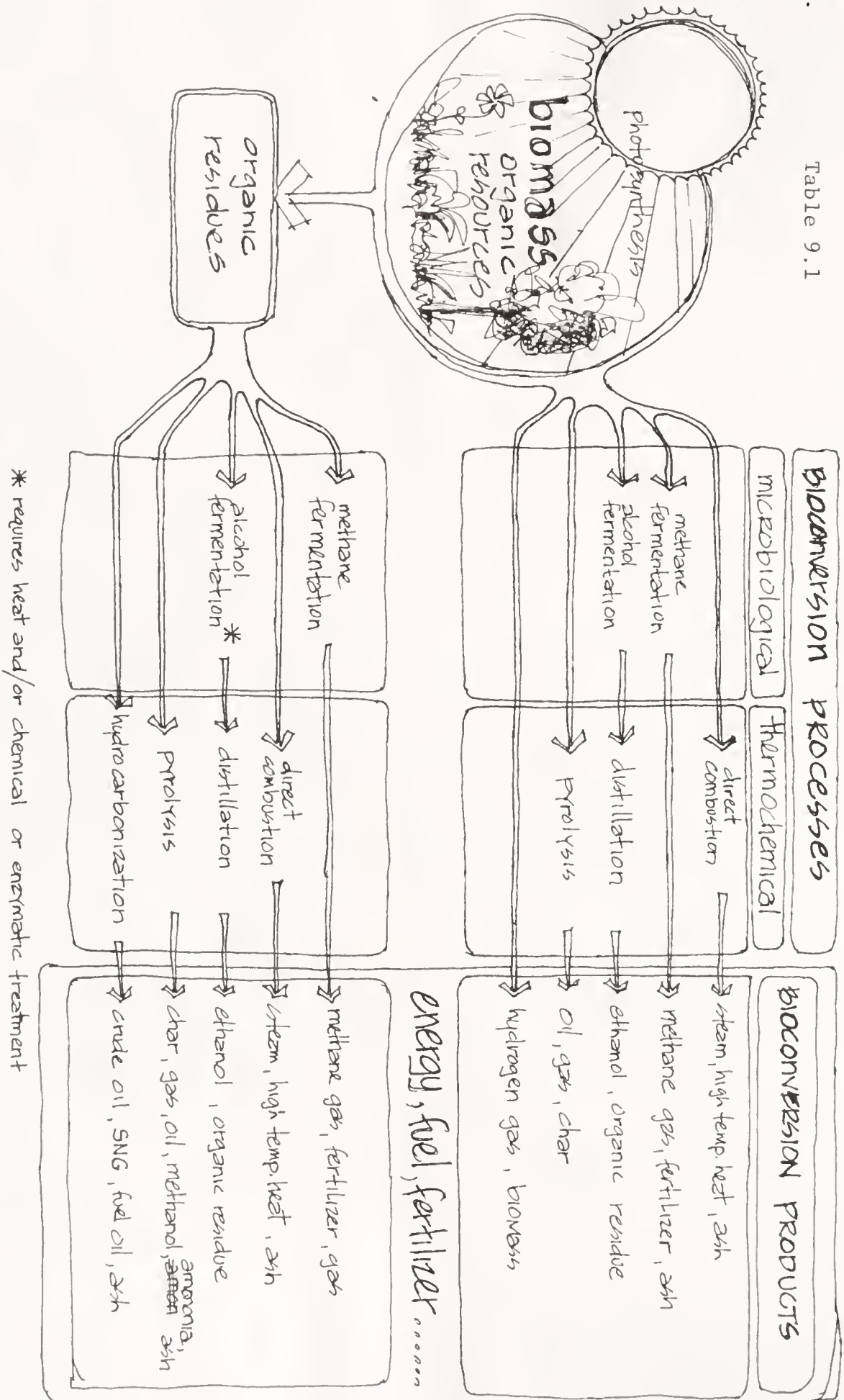
9.1 Introduction

Biomass is the product of photosynthesis; it is for the most part dependent on the sun. "Photosynthesis is the biological process by which green plants use the energy of the sunlight--the quanta--to convert carbon dioxide to the higher energy carbon-hydrogen bonds of carbohydrate and other organic compounds" (Calvin, 1976). This biomass forms the basic organic compound for the geological transformation of fossil fuels -- coal, oil, gas -- which are presently our major sources of energy.

Biomass can be converted, using existing technologies, to replace fossil fuels currently in use. This is especially significant where certain low-volume-to-energy-content fuels are required, as is the case for mobile equipment or transportation purposes where liquid fuels are essential. If requirements dictate a fossil fuel substitute, bioconversion (even at lower efficiency) can supply chemical energy which is not available from other forms of solar energy such as direct radiation, wind, or water.

The theoretical upper limit of photosynthetic conversion of light quanta to biomass is eight percent for the most efficient plants (C_4) and five to six percent for C_3 plants. In actual observed performance, the conversion efficiency of most C_4 plants is two percent and for C_3 plants it is one percent. In comparison, direct conversion of sunlight to low and medium temperature thermal energy using solar collectors is forty to fifty percent efficient. (Greeley, 1976)

Table 9.1



In the past, with extreme scarcity of fossil fuel sources, biomass technologies have proven to be viable substitutes. During wartime, alcohols -- methanol and ethanol (Pollard, 1976) -- as well as biogas (Tietjen, 1975) and wood (Glesinger, 1947) served as petroleum substitutes. These past experiences clearly indicate when a concentrated, chemical form of energy is desired, fuels from biomass demonstrate a distinct advantage over other forms of renewable energy.

For the purpose of analysis, three generic types of bioconversion will be discussed; these represent a comprehensive assessment of the "state of the art" in the area. These are:

Thermochemical: 1) Direct combustion
(Section 9.2.1)

2) Pyrolysis

3) Hydrogenation

Microbiological: 1) Methane fermentation
(Section 9.2.2)

2) Alcohol fermentation

Photochemical: 1) Hydrogen from photolysis
(Section 9.2.3)

9.2 Conversion Processes

9.2.1 Thermochemical

All organic sources lend themselves to combustion, although moisture content is an important factor in practicality, very wet materials such as fecal material, food waste and aquatic plants require additional energy for drying, which can contribute to additional energy and capital equipment at reduced efficiency. Those resource materials requiring the least preparation are best suited for combustion. The following are listed, in descending order of desirability, for bioconversion by combustion:

Table 9.2
Moisture Content of Resource Materials

Moisture Content	Resource Material
0-20%	wood, wood waste, paper waste, straw, dry sludge (sewage or animal manure)
20-50%	urban solid waste, forest residue, other wood waste, crop residue
50-90%	urban solid waste, pulp waste, sewage, manures, aquatic plants

Direct burning of concentrated waste is not only a very efficient use of certain resources, but it is also an existing and widely used technology in the forest products industry. In fact, several boiler manufacturers actively promote and sell boilers to utilize a variety of biomass fuels ranging from sanding dust,

sawdust, chips, bark, and hog fuel to mixed urban solid waste (Hall, 1976).

At least three Montana forest products industries already utilize either wood waste from their processes or purchase other wood waste such as bark for direct burning. This fuel is used both for process steam and for electrical power production (Henningson, 1976).

Table 9.3

Comparison of Heat Values of Solid Fuels in Montana

Resource Area	Specific Material	Moisture	BTU/lb.	Reference
Wood:	Hardwoods	12%	8,500	de Zeeuw (1976)
	Conifers	12%	9,000	de Zeeuw (1976)
Crop Residue:	Wheat straw	10%	8,500	Newman (1967)
	Corn Cob	15-18%	8,200	Newman (1967)
Solid Waste:	Combustible fraction (paper, garbage, plastics, etc.)	35.2%	5,000	Henningson (1976)
Animal manure:	Bovine fresh:	80-90%	5,000-	Halligan (1974)
	feedlot:	15-37%	6,000	
	Swine	75-80%	n/a	
	Poultry	55-75%	n/a	
Sewage:	Raw sludge	n/a	3,700- 7,300	Merrill (1974)
	Digested sludge	n/a	3,800- 6,900	Merrill (1974)
Coal:	Eastern Montana		8,000	Henningson (1976)
	Southern Wyoming		10,500	Henningson (1976)

9.2.1.1 Direct Combustion

Direct combustion yields the highest amount of energy in the form of high temperature heat which can be extracted from the biomass material. 65-80% of the fuel value of wood can be realized with existing boiler technology. Both fuel value and efficiency depend on the moisture content of the wood (Hall et al., 1976). The fuel value of an organic material such as wood depends primarily upon its volatile matter in the dry cell-wall membrane, tannin and resin. Moisture content, of course, decreases this value because of the heat lost to vaporize water. This is true for other biomass types. For wood, the approximate relationship of moisture is given by the formula:

$$\text{BTU per pound} = H \frac{100 - (\text{m.c.}/7)}{100 + \text{m.c.}}$$

where H is the heat of combustion

m.c. is the moisture content of wood in percent (%).

In the case of wood, H is 8,500 BTU for hardwoods and 9,000 BTU for conifers. This is based on dry matter with 12% moisture content (deZeeuw, 1967). Other resource materials such as solid waste, crop residues, and manure will also fit this general formula.

Table 9.4
Fuel Values for Wood at Different
Moisture Contents

Moisture Content % (wet basis)	Heating Value	
	medium	low
0	8,500	7,000
5	8,075	6,650
25	6,375	5,250
50	4,250	3,500

Source: Hall et al., March 1976, p. 5

An additional penalty of moisture is added weight. This results in a proportionate decrease in its heat value per unit volume for burning.

Direct combustion of the different biomass and organic residue resources can yield a variety of useful energy products. The three most important and useful types of energy available from direct combustion are as follows:

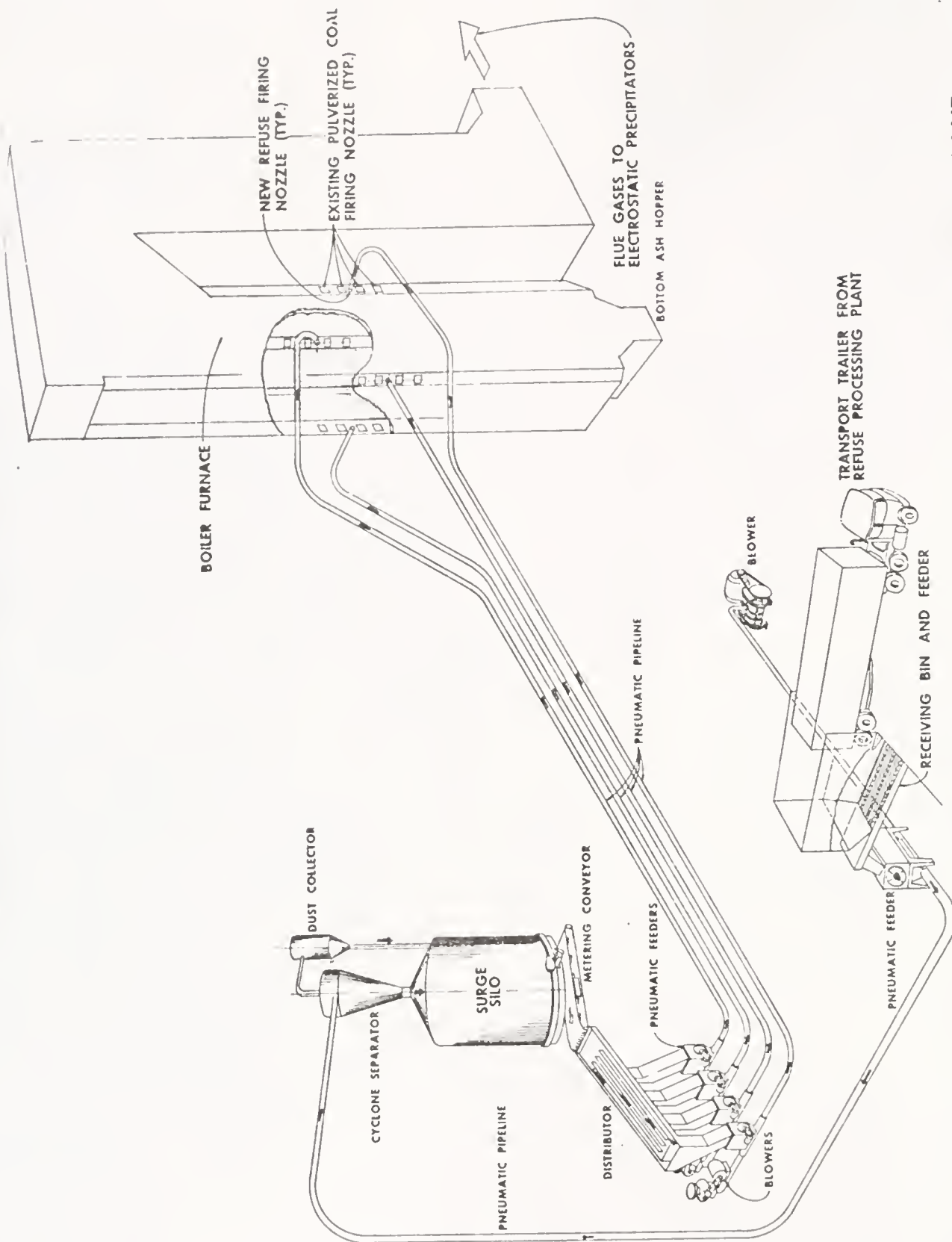
1. Electricity
2. Steam process heat
3. Direct heat

The type of energy desired is obviously a choice based on needs and scale of operation.

9.2.1.1.1 Electricity can be generated from biomass or organic residues through direct combustion for high temperature heat to make steam for turbine generators. The technology for this application is well established. Several working prototypes or full-scale demonstration units are currently operating. These are listed below and described in Table 9.5.1.

9.2.1.1.1.1 St. Louis-Union Electric: This system utilizes shredded and sorted solid waste as a supplemental fuel in the existing coal and gas-fired boilers. The addition of a single solid waste firing port to the existing four coal ports and five gas ports is a simple modification to adapt the twenty-year-old boilers to this new application. Solid waste accounts for ten percent of the fuel consumption of the two 125 Mwe boilers at a daily savings of 300 tons of coal (Kash, 1975).

9.2.1.1.1.2 A planned facility for Wilmington, Delaware will utilize a combination of solid waste, industrial waste and dried sewage sludge to supplement an existing oil-fired boiler. This unit will be operational by 1977.



BASIC LAYOUT OF REFUSE UNLOADING, METERING AND FEEDING FACILITIES AT POWER PLANT

Figure 9.1
 Direct Combustion Solid Waste Process at Union Electric Co.,
 St. Louis, MO
 Source: Reprinted from Horner and Shiflett, Inc., 1973

9.2.1.1.1.3 C&C Plywood Corp. of Kalispell, Montana has plans to install a system to generate electricity and steam for dryers. This system is expected to produce an estimated 7.7×10^6 Kwh/year or 2.6×10^{10} BTU/year. Fuel for this system will consist primarily of wood waste from the manufacturing operation and bark, which is locally available at a very low cost of about \$0.05/MMBTU.

9.2.1.1.1.4 The St. Regis Company in Libby, Montana, presently consumes 370,000 tons of hog fuel each year. They are able to supply 99% of their fuel requirements with this wood residue resource. Two-thirds of this is converted into process steam with the remainder being further converted by turbines into electricity.

9.2.1.1.1.5 The Horner-Waldorf Corporation in Missoula, Montana uses a combination of fossil fuels and wood residues to generate steam and electricity. The following list indicates their fuel mix for a year.

Fuel	% Total	Remarks
Natural Gas	33	4.6×10^6 MCF
Spent Liquor	57	Turpentine distillate
Hog Fuel	9	Kraft & pulp residue
Fuel Oil	1	172,000 gallons

Table 9.5.1

Comparison of Commercial and Existing Prototype Units
for Direct Combustion to Produce Electricity

Name, company or process	Primary Resource Used	Maximum Daily Loading	Energy and/or By-Products	Process Efficiency*	Reference
St. Louis MO (Union Electric)	Mixed, wet solid waste	650 tons**	electricity (supplement to coal-fired boiler)	steam 86.4% electricity 35- 38%	Horner & Shifner (197 Kash et al. (1975)
Wilmington, Delaware	Mixture of: 1. solid waste 2. industrial waste 3. sewage sludge (dewatered)	1. 500 tons 2. 15 tons 3. 230 tons ----- 845 total tons	electricity (supplement to oil-fired boiler)	steam 80% electricity 35- 38%	Kash et al (1975)

*Process Efficiency = $\frac{\text{BTU value of energy output}}{\text{BTU value per pound dry matter of the resource + other process energy inputs}}$

**Prepared refuse -- nominal generation rate for St. Louis is 410 tons/day (Horner & Shifrin, Inc., 1973)

Table 9.5.1 (cont.)
Comparison of Commercial and Existing
Prototype Units for Direct Combustion
to Produce Electricity

Name, company or process	Primary Resource Used	Maximum Daily Loading	Energy and/or By-Products	Process Efficiency	Reference
C&C Plywood Corp. Kalispell, MT	Bark & Wood Residue	4.5 tons (8000 BTU/lb.)	Electricity & steam	35-38% 65-85%	C&C Plywood, 1976
St. Regis Libby, MT	Hog fuel	1000 ton (5000 BTU/lb.)	Steam (67%) Electricity (33%)	65-85% 35-38%	St. Regis, 1976
Hoerner-Waldorf Corp. Missoula, MT	Spent liquor Hog fuel	157 tons 300 tons	Steam (76%) Electricity (33%)	65-85% 35-38%	Hoerner-Waldorf 1976

Table 9.5.2

Comparison of Commercial and Existing Prototype Units
for Direct Combustion to Produce Steam

Name, process or company	Primary Resource Used	Maximum Daily Loading	Energy and/or By-Products	Process Efficiency*	Reference
Evans Products Company Missoula, MT	Sander dust Sawdust Shavings	n/a	Steam heat	65-85% 65-85%	Evans Products Company, 1976
Plum Creek Lumber Columbia Falls, MT	Shavings & Sawdust Bark	150 tons 75 tons	98% steam	65-85%	Plum Creek Lumber, 1976

*Process Efficiency = $\frac{\text{BTU value of energy output}}{\text{BTU value per pound dry matter of the resource + other process energy inputs}}$

9.2.1.1.2. Process steam at 65% - 80% conversion efficiency is probably the best way to use direct combustion of biomass and organic residues. This is a tried and proven method of utilizing residues from the timber industries throughout the country. At least five companies, including the three mentioned in the previous section, use wood and factory residues to generate their own process steam.

9.2.1.1.2.1 Evans Products Company, Missoula, Montana, a particle board manufacturer, uses dry shavings and sawdust to directly fire three ovens for drying and a boiler for process steam. The three direct fire ovens operate from six to eight hours for five days using a small amount of natural gas as a supplement to the residue fuel. The boiler outputs 15,000 pounds per hour for process steam and 25-27,000 pounds per hour for heating when required. The boiler operates full time (i.e. seven days) using sander dust as its prime fuel source. Dryers run at 25,000,000 to 50,000,000 BTU/day using direct fire from shavings and sawdust.

9.2.1.1.2.2 Plum Creek Lumber Company of Columbia Falls, Montana, fires its 100,000 lbs/hr. boiler with 150 tons of shavings and sawdust which are residues from its operation. In addition, the company purchases 75 tons per day of bark at a cost of \$0.04 per mm BTU. Ninety-eight percent of this is consumed to produce process steam.

9.2.1.1.3 Direct heat from combustion of biomass and organic residues will have its greatest impact on space heating for residences. Several proven techniques are available for use.

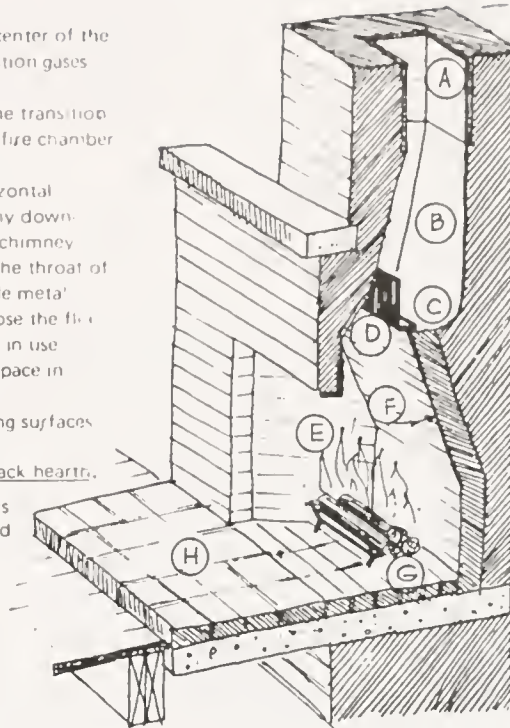
Table 9.5.5
Biomass Heat Production Techniques
for Residences

Type Unit	Expected Efficiency
Masonry Fireplace	Negative to 10%
Metal Fireplace	Negative to 25%
Closed Stove	25% to 50%
Complete Combustion Stove	40% to 80%

9.2.1.1.3.1 Traditional fireplaces are usually negative contributors to heating residences. Quite often they draw more heat from the room than they can contribute since they are largely limited to providing heat from radiation to a small area directly in front of the hearth, while drawing air from the room to support combustion. Masonry fireplaces can be made or modified, however, to provide up to about 30% efficiency for space heating. Measures which can be taken to improve conventional fireplace performance are listed below in succeeding order of importance.

1. Air for combustion should be provided from outside the heated space. This can be air from outside or from an unheated basement or crawlspace.
2. Metered control of draft is essential to efficient combustion. This can be accomplished by either a glass or solid metal screen in front of the fireplace opening.
3. Radiant energy will be lost with a glass covering the opening

- A. The flue, or the hollow center of the chimney, carries combustion gases out of the house.
- B. The smoke chamber is the transition area which connects the fire chamber with the flue.
- C. The smokeshelf is a horizontal surface which deflects any down-drafts coming down the chimney.
- D. The dampener, located in the throat of the chimney, is a movable metal plate which is used to close the flue when the fireplace is not in use.
- E. The fire chamber is the space in which the fire burns.
- F. Firebrick is used for lining surfaces near intense heat.
- G. The fire is built on the back hearth.
- H. The front hearth protects the floor from sparks and embers.



parts of a traditional fireplace

Figure 9.2

Traditional Fireplace

Source: reprinted from The Energy Primer, Dahlin, 1972

Figure 9.3

Example of a Metal Circulating Fireplace

Jøtul System 15

System 15 will heat twice as well as a traditional fireplace. Install it allowing for a heating chamber behind the firebox. Heat is forced from the heating chamber into the room through vents above the fireplace. Tests at the Jøtul factory show that the traditional fireplace draws about 90% of the heat up the chimney, and allows 10% into the room. In other words, it has 10% heating efficiency. System 15 has 20% heating efficiency. A free-standing fireplace has about 25% and boxstoves have 40-60%. These figures vary somewhat depending on design and draft, but nonetheless, for those who wish a built in fireplace and some heat too this is the answer!

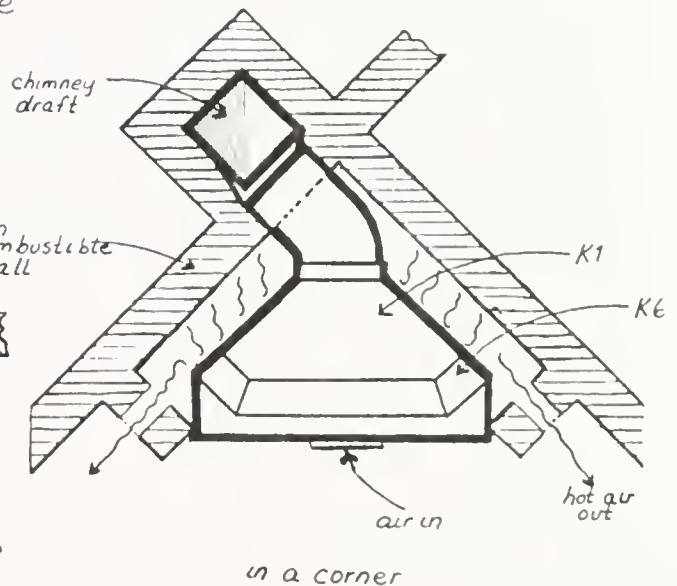
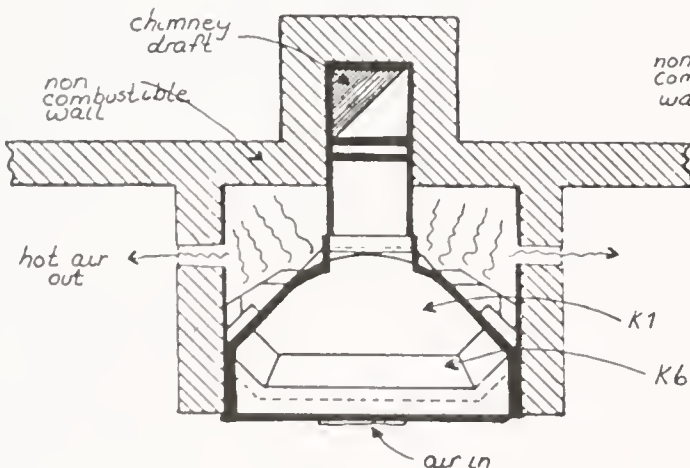
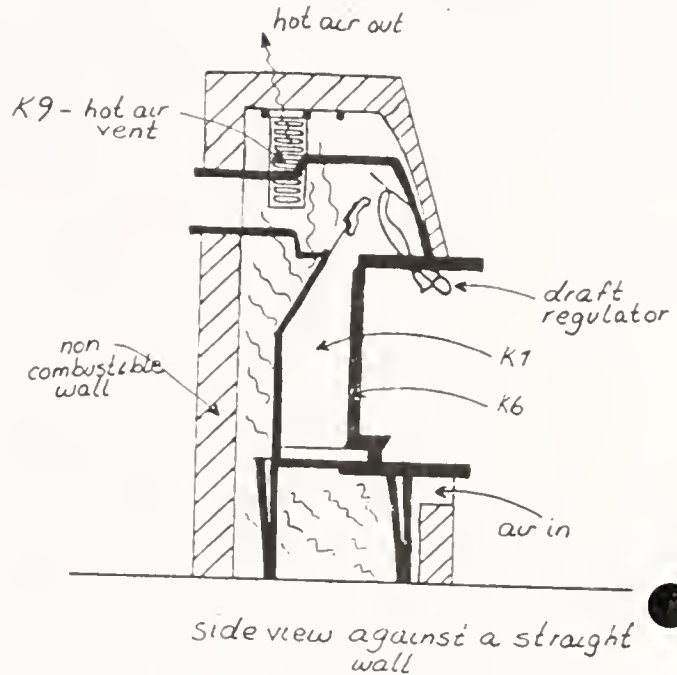
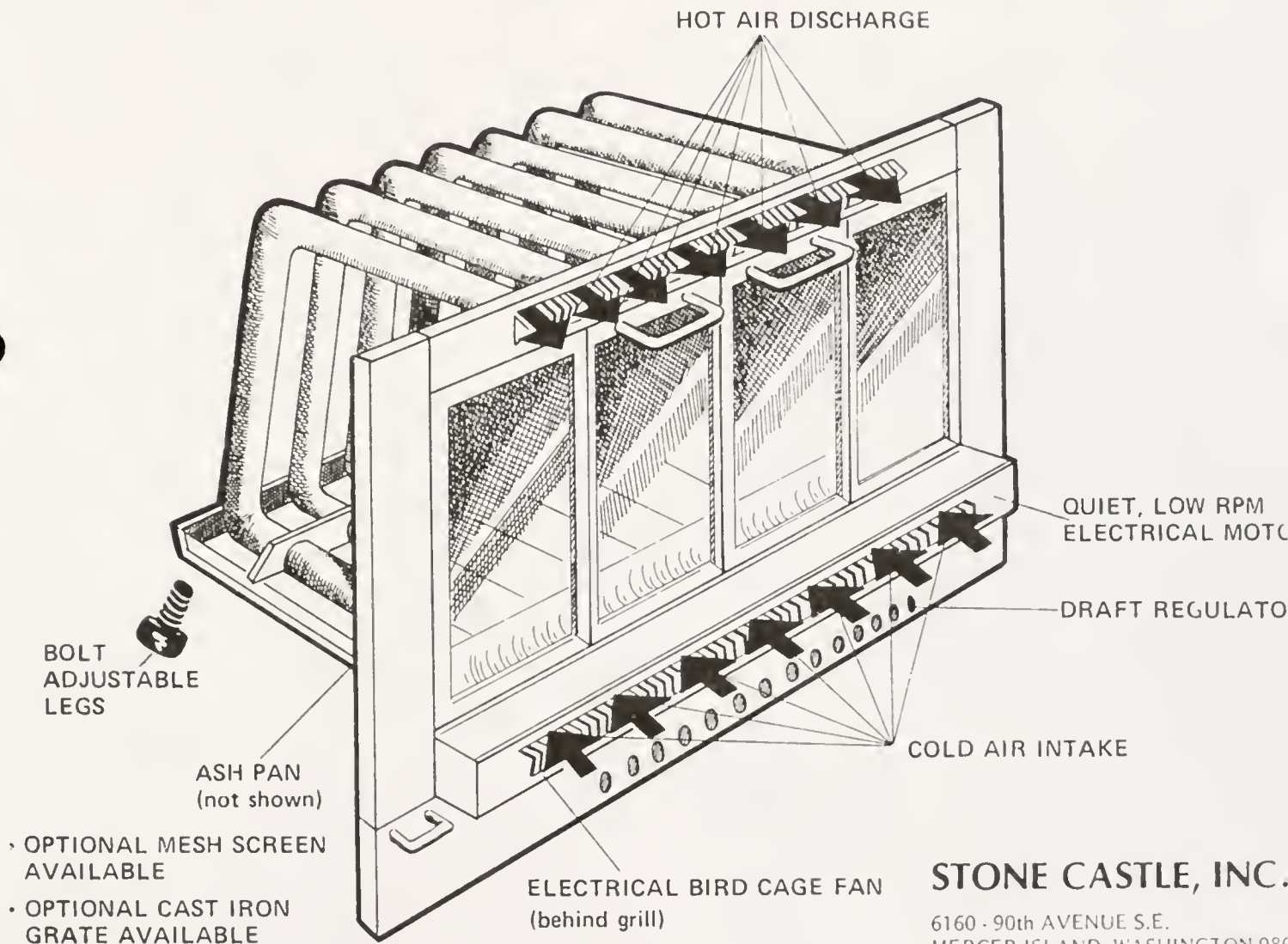


Figure 9.4

Example of a Draft Control Insert for Traditional
Fireplaces,
featuring either forced air or free-convection
heating

Dual Action Fireplace Furnace



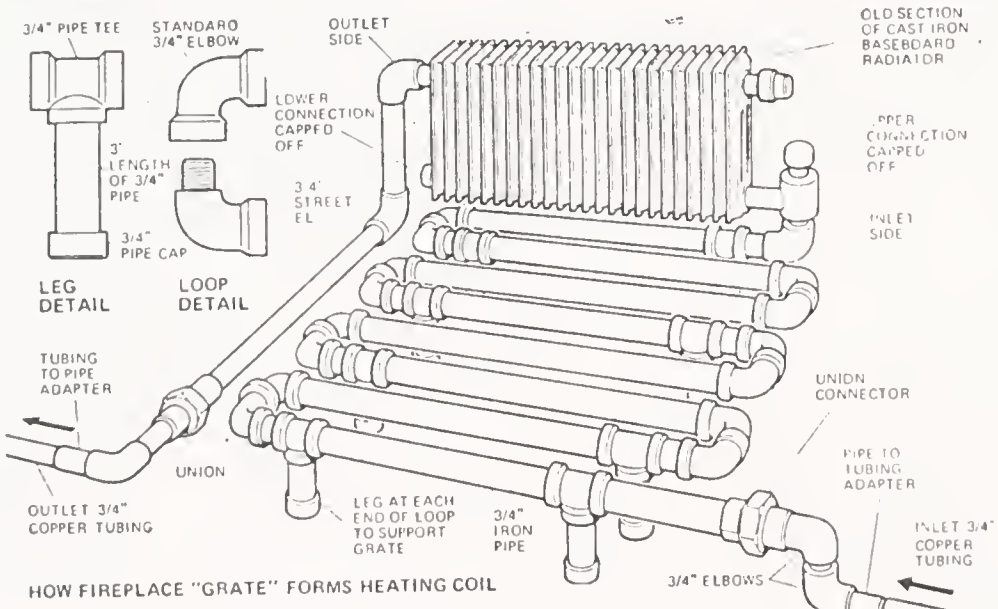
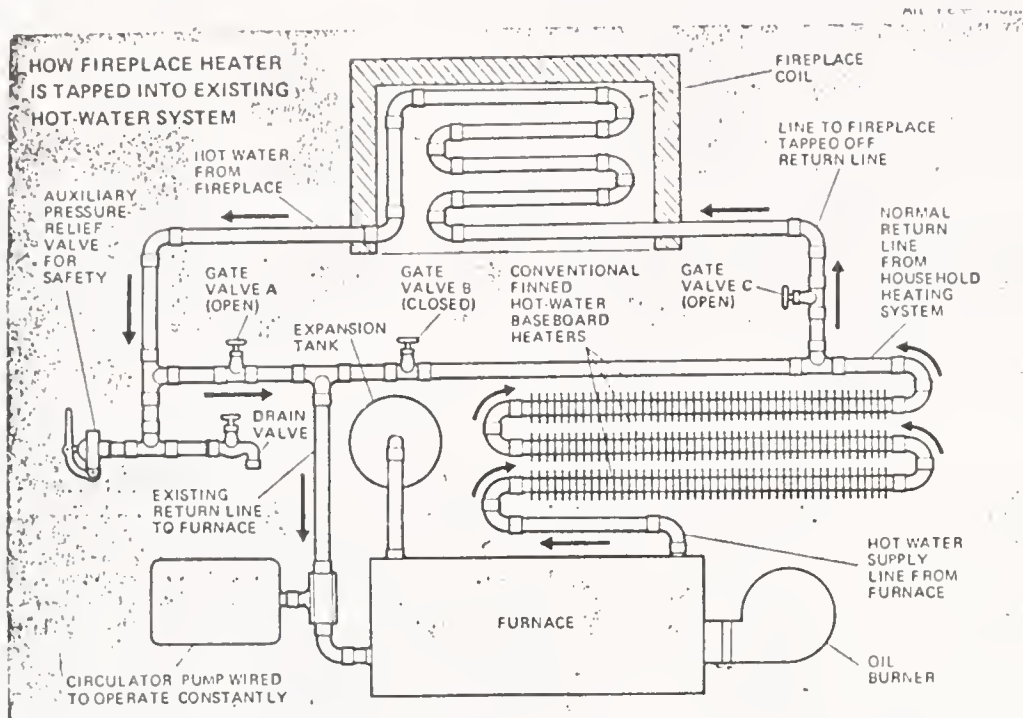
STONE CASTLE, INC.

6160 - 90th AVENUE S.E.
MERCER ISLAND, WASHINGTON 98040

Source: Advertisement for Stone Castle, 1976

Figure 9.5

Fireplace Furnace: A Good Example of a Home Made Heat Exchanger for a Traditional Fireplace



Source: reprinted from Popular Mechanics, Oct. 1974

to the fireplace. It is, therefore, necessary to have some kind of heat exchanger to effectively remove heat from the fireplace. Several commercial and homemade devices are applicable in this situation. A metal enclosure with convection vents is a common item used to improve fireplace performance. A homemade option is to install a pipe radiator to extract heat as hot water that can be transported by pump or free convection to an external radiator for room heating.

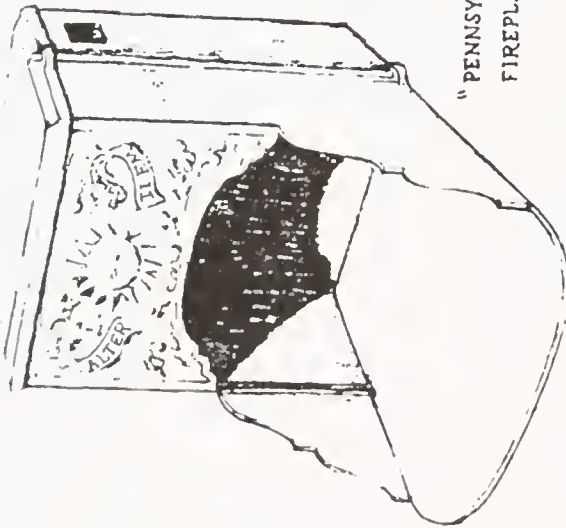
Fireplaces are not likely to exceed 30% efficiency even when all of the above corrective actions have been taken. This limit of performance is mainly a consequence of inadequate combustion resulting from poor design in the fireplace as a combustion chamber. The more advanced "complete combustion" stoves are especially designed to utilize all of the available volatile material in the wood.

9.2.1.1.3.2 Metal or free-standing fireplaces suffer from the same design limitations as their more traditional masonry cousins. These drawbacks include poor combustion chamber design, poor draft control and reliance on heated space air for combustion. The advantage of a freestanding metal fireplace is that, first, it has more surface area to radiate heat to the space, and, second, that draft control is often an option, especially where a "Franklin" type fireplace is used.

In 1740, Benjamin Franklin, inspired by a threat of firewood shortage, designed the famous "Pennsylvania Fire-Place". "Clearly the Pennsylvanian fireplace bears little resemblance to today's 'Franklin' stove, and use of his name that would cause Ben to shudder" (Gay, 1974). Franklin's design (Figure 9.6) was clearly advanced. He reduced the fireplace opening with a shutter sliding in grooves

Figure 9.6

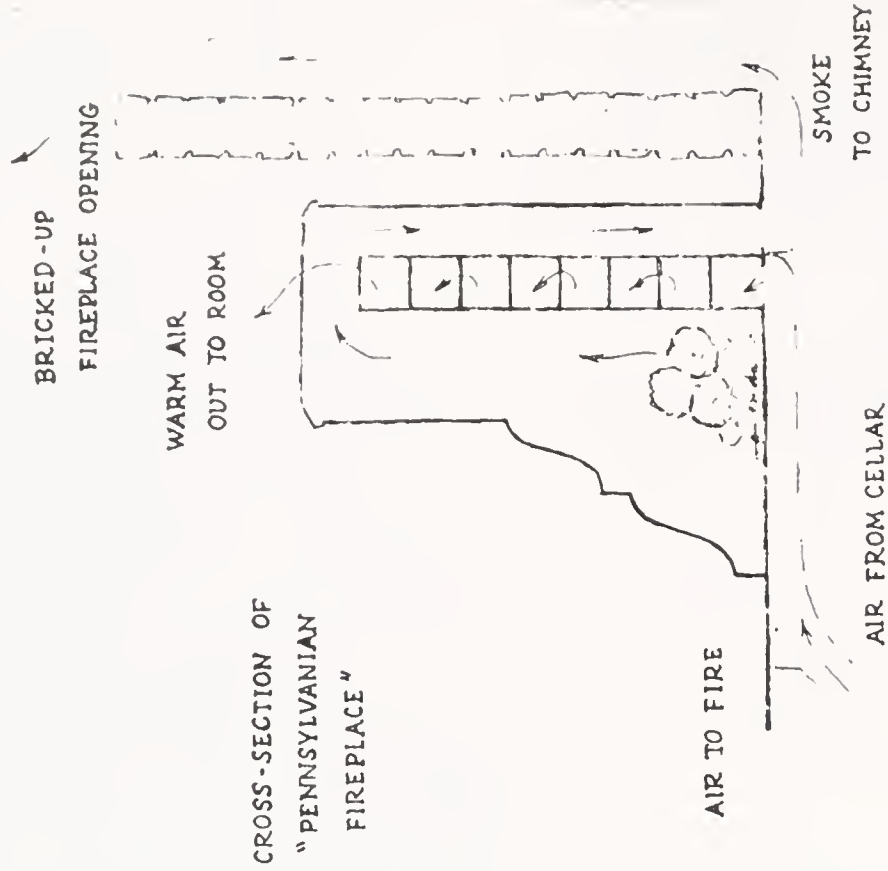
The "Pennsylvania Fireplace"



"PENNSYLVANIAN
FIREPLACE"

"In common chimneys, the strongest heat from the fire, which is upwards, goes directly up the chimney, and is lost; and there is such a strong draft into the chimney, that not only the upright heat, but also the back, sides, and downward heats are carried up the chimney by that draft of air; and the warmth given before the fire, by the rays that strike out towards the room, is continually driven back, crowded into the chimney, and carried up by the same draft of air. But here the upright heat strikes and heats the top plate, which warms the air above it, and that comes into the room. The heat likewise, which the fire communicates to the sides, back, bottom, and air-box, is all brought into the room; for you will find a constant current of warm air coming out of the chimney corner into the room." —Benjamin Franklin

Source: reprinted from Gay, 1974

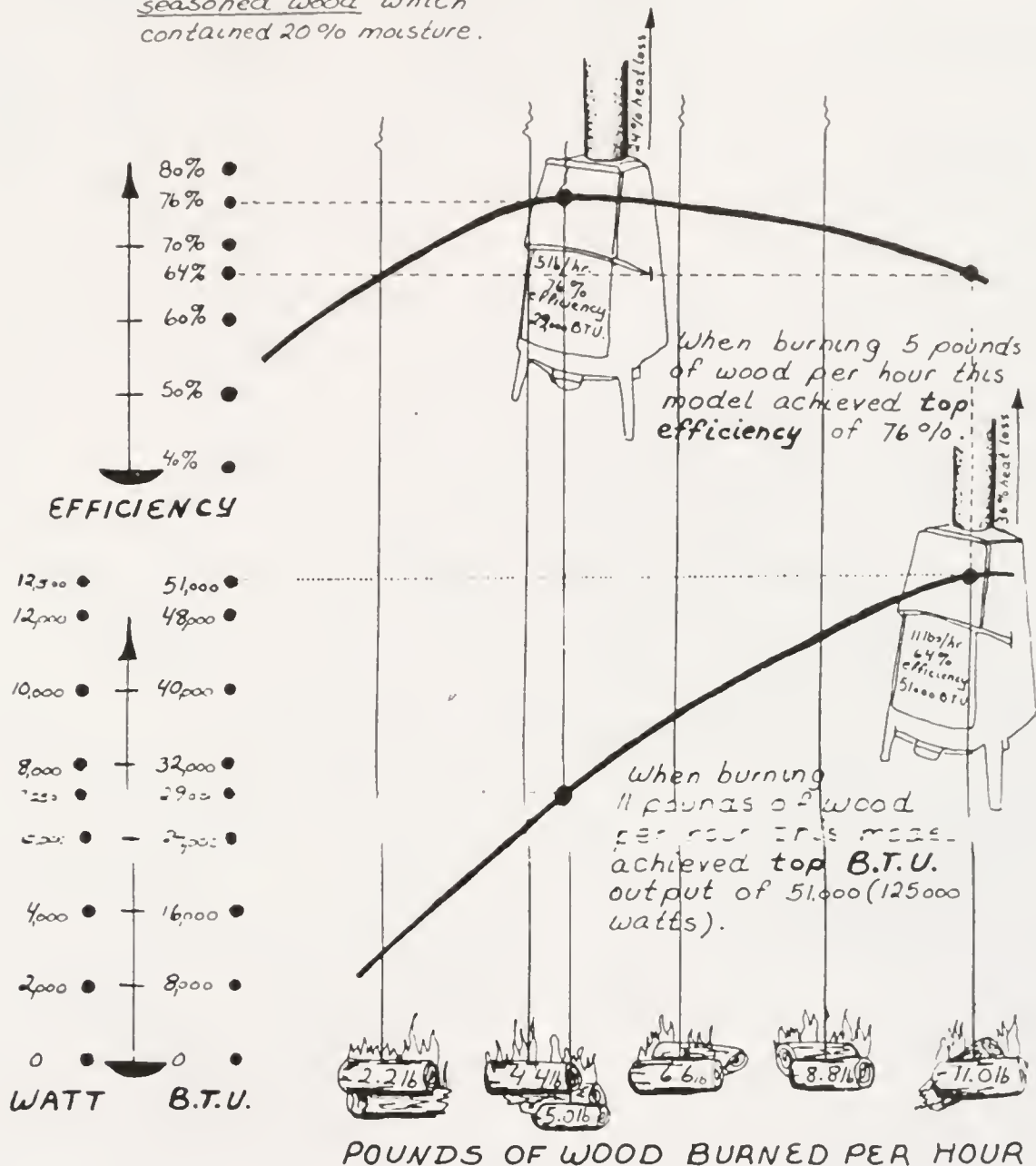


This was the original metal insert for traditional fireplaces with a free convection room air heater.

A Free-standing Fireplace which Can Be Closed and Used
as an Air-Tight, Complete Combustion Stove

Testing Results on Combi-fire 4^(TM) Jøtul

This test was done with
seasoned wood which
contained 20% moisture.



These results were given to
Kristia Associates by
Eiler Granum of Jøtul Inc
Testing Laboratory, Oslo, Norway
November 5, 1974
Interpreted by Kristin Horton.

to restrict the draft; the design created an "air-box" to heat and circulate room air. Fresh air was taken from the basement through a heat exchanger chamber to heat the room and to increase burning efficiency. Heated air entered the room at the top on both sides.

One unusually efficient type of freestanding fireplace, the Jøtul (TM) "combi-fire" can be closed and controlled as a complete combustion type stove (CCS). As a CCS, the "combi-fire" has achieved a measured efficiency of 76% at a burning rate of five pounds per hour, with an output of 29,000 BTU/hour (Kristia, 1975).

Typically, however, freestanding fireplaces range from negative up to about 30% efficiency.

9.2.1.1.3.3 The closed wood stove is best illustrated by the ever-popular "pot-bellied" stove. These are characterized by being enclosed combustion chambers with greatly reduced openings for fuel supply and, consequently, greater draft control. Homemade versions of closed stoves are exemplified by the common conversion of a 55 gallon oil drum into a stove. The efficiency of this type of stove is dependent on the tightness of fit on the combustion chamber door and the draft control. These stoves generally range from 25% to 50% efficiency.

9.2.1.1.3.4 The complete combustion stove is one in which special draft control, firebox design, and airtight construction insure that almost total combustion of the volatile matter in the wood is achieved. It is first essential that the design is airtight. This insures that the next criteria, draft control, can be maintained. Frequently, draft control is accompanied by a bimetallic thermostat which meters the air intake. That is, however, not entirely necessary as long as some tight control is possible.

Figure 9.8

A Complete Combustion Stove with Thermostatic Control

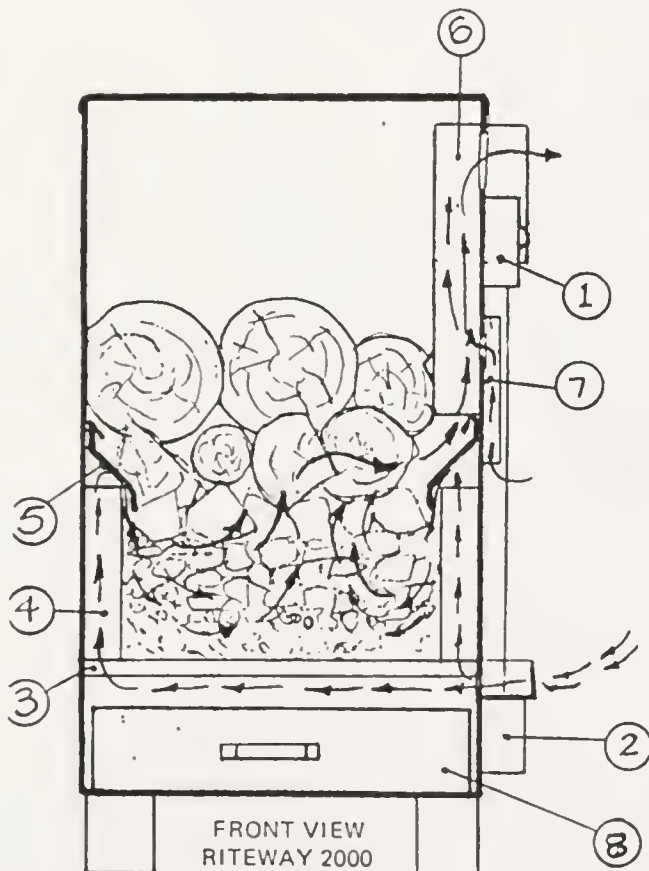
'COMPLETE COMBUSTION'

The Riteway 2000 retains all the time-tested complete combustion features that have made Riteway the aristocrat of woodburning heating equipment.

Some manufacturers claim to achieve complete combustion in their products, but only in Riteway do you find the sophisticated design and quality construction required for complete combustion to take place.

Our experience in manufacturing wood heaters spans nearly four decades, and the result is that we've got the finest heater there is on the market.

Take a look at the cross-section and explanatory notes below. We know you'll be impressed!



- (1) The Riteheat Regulator—simply set the dial for the temperature you want. A bi-metal coil inside the regulator raises a chain connected to the magnetic damper (2).
- (2) The magnetic damper—automatically admits air when Riteheat Regulator calls for heat. Air travels below the grate (3) and behind the liners (4).
- (3) Grate—protected by 2-3 inch layer of ash at all times.
- (4) Liners—Air travels upward behind the liners and then is deflected into the combustion chamber by the liner retainers (5).
- (5) Liner retainers
- (6) Gas combustion flue—smoke is forced downward back into fire before it can enter the combustion flue and exit out the chimney.
- (7) Secondary air enters through this duct where it is preheated before entering the combustion flue. The secondary air provides the oxygen necessary for complete combustion to occur.
- (8) Ash pan—constructed from corrosion-resistant aluminized steel. Will last a lifetime.

Another criterion is a combustion chamber design which encourages the secondary combustion of volatile gases which are the products of initial combustion. Usually a secondary burning chamber is provided where volatile gases are combusted by the addition of a secondary draft of fresh air. Another important aspect of the complete combustion stove is its ability to maintain a continuous fire overnight. Because of draft controls, these stoves can be turned down to a very low level in the evening before bedtime and sustain a fire into the morning.

The increased popularity of this type of woodburning stove has created a renewed boom in their sale and manufacture. The availability of both the domestic models and the Scandinavian imports has greatly increased in the past two years. Several domestic manufacturers are now offering a complete line of basement-style furnaces and boilers which feature the complete combustion design. Some of these furnace/boilers are also available with automatic switchovers to gas or oil-firing burner if the wood fuel is exhausted.

The wood stove manufacturers guide, Table 9.5.5, is not meant to be exhaustive, but rather it is representative of what is available. Table 9.5.6 is a list of manufacturers or distributors which is nearly complete.

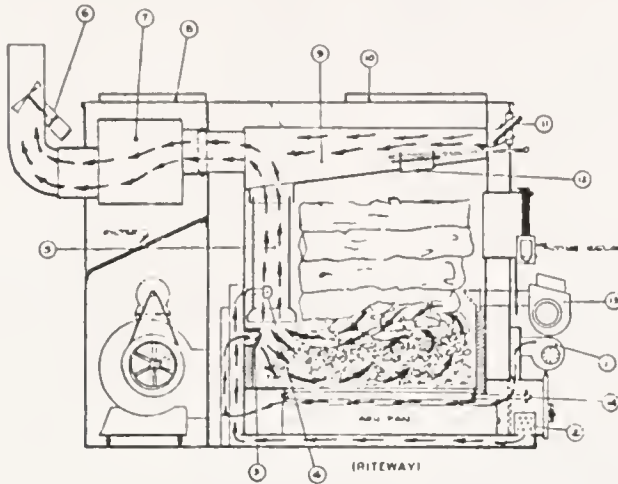
Figure 9.9

Complete Combustion Furnace And Boiler

RITEWAY FURNACES

Familiarize yourself with the operational principles of Riteway furnaces by studying the drawing and the corresponding numbered notes below.

1. Ash pit blower controlled by room thermostat creates forced draft in the combustion chamber. Air enters through two cast iron ports (3) located on either side of the gas combustion flue (5). Burning fuel in a back-to-front pattern maintains a very hot zone in the gas combustion flue. This is necessary in order to completely combust the gases, which if left unburned, cause creosote deposits.
2. Secondary air enters here, passes through space under the furnace and upward through a small duct into the gas combustion flue (4).
3. Cast iron air ports which direct the flow of primary air from the back toward the front of the combustion chamber.
4. Cast iron secondary air duct.
5. Heavy cast iron gas combustion flue located completely inside combustion chamber, insuring high temperature necessary to burn the gases.

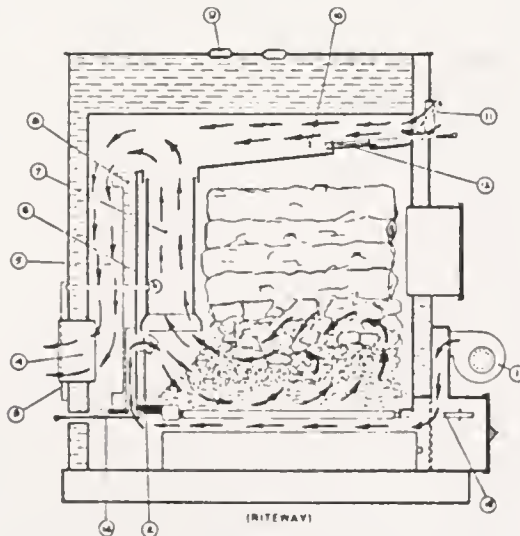


6. Draft inducer operates constantly to guarantee sufficient secondary air under all draft conditions, lessening any difficulties with creosote.
7. Return air is preheated at the heat exchanger before passing through the filter and into the blower, which in turn forces it over the furnace body.
8. Opening for return air plenum in top of fan chamber.
9. Bypass air flue in top of furnace.
10. Opening in top of furnace for warm air plenum.
11. Barometric damper permits a continual flow of air into the bypass air flue. The dry warm air is mixed with flue gases and helps in preventing the smokepipe and chimney from sweating, something essential in avoiding creosote deposits.
12. Direct draft damper located near top of fuel door. This damper should be open when adding fuel to prevent smoke from escaping into the furnace room.
13. Optional oil or gas burner mounted to left side of fuel door. Special stainless steel damper operated by the heavy duty solenoid isolates burner from the combustion chamber when burner is not in operation. If wood fails to maintain the desired temperature, a room thermostat can automatically energize the solenoid and oil burner to supply required heat until wood supply is replenished.
14. Specially designed grate bars made for lifetime service.

RITEWAY BOILERS

Study the operational principles behind Riteway boilers using the cross-section, and corresponding numbered notes below.

1. The ash pit blower, which provides a forced draft, is usually operated by an aquastat maintaining the desired water temperature. The blower may be operated by a room thermostat, if the unit is a gravity-type boiler. The air travels from the ash pit blower into the ash pit and upward through two air ports on either side of the gas combustion flue. The flow of air helps to create a back-to-front burning pattern, which in turn, maintains the very hot zone around the gas combustion flue needed to burn the wood gases.



2. Two cast iron air ports which direct the flow of primary the combustion chamber.
3. Secondary air duct which supplies air to the distributor in the gas combustion flue (6). The preheated secondary air provides the necessary oxygen for completely burning the wood gases.
4. Smoke pipe collar at rear of boiler.
5. Flue gases flow down this heat chamber and pass out through the smoke pipe opening (4).
6. Cast iron air distributor for secondary air.
7. Heavy cast iron gas combustion flue is mounted entirely within the combustion chamber in order to maintain the high temperature necessary to burn wood gases.
8. Thick plates welded to these two water circulating tubes form a downdraft chamber and provide long fire travel. The steel plates also aid in conducting heat to the tubes.
9. Flow tappings on top of boiler.
10. Bypass air heating flue.
11. Barometric damper prevents excessive draft on boiler during windy weather. The dry warm air is mixed with flue gases and helps prevent sweating in the smokepipe and chimney.
12. The direct draft damper helps prevent smoking when starting a fire or adding fuel.
13. Extra heavy grate bars made for lifetime service.
14. Fuel selector damper permits shifting draft when burning coal or wood.

Table 9.5.4

Comparison of Commercial and Existing Prototype Units for
Direct Combustion: Wood-Burning Space Heaters

Name, company or process	Primary Resource Used	Maximum Daily Loading	Energy and/or By-Products	Process Efficiency*	Reference
Common masonry fireplace	Wood	250 lbs.	Low temperature space heat	Negative to 10%	Dahlin, 1974
Circulating metal fireplace with draft control	Wood Residue	250 lbs.	"	Maximum 30% (with draft control)	
Franklin Stove" (example of free- standing metal fireplace)	"	250 lbs.	"	Maximum 30% (with closed doors)	
Closed stove "pot bellied"	"	200 lbs.	"	Maximum 50%	
Jøtul (TM) -- complete combus- tion stove	"	250 lbs.	"	64-76%	Kristia, 1975
Riteway (TM) Complete com- bustion furnace or boiler	"	750- 1500 lbs.	"	65%	Riteway, 1975

*Process Efficiency = $\frac{\text{BTU value of energy output}}{\text{BTU value per pound dry matter of the resource + other process energy inputs}}$

Table 9.5.5

Woodstove Manufacturers Guide

Legend of stove types:

FSF: Freestanding Fireplace

CS: Closed Stove

CCS: Complete Combustion Stove

MFP: Metal Insert for Conventional Fireplace

Manufacturer or Distributor	Brand Name	Type Stove	Cost	Remarks
The Majestic Co. Huntington, IN 46750	Thulman Fireplace (TM)	MFP	\$258-\$326	Non-circulating with external air supply through the chimney
The Majestic Co.	Circulator Fireplace (TM)	MFP	n.a.	Recirculation of room air by natural convection or by forced fan optional
Stone Castle, Inc. 6160 - 90th Av., S.E. Mercer Is., WA 98040	Dual Action Fireplace Furnace	MFP	\$370	Made to be inserted into conventional masonry fireplaces. Draft control and forced or convection air circulating heat exchanger. Increase fireplace efficiency to approximately 30%.
Popular Mechanics October 1974	"Fireplace Furnace Heating Your Home"	MFP	n.a. est. \$150-\$200	Homemade water heat exchanger attached to existing boiler and radiant hot water system.
Autocrat Corp. New Athens, IL	Americana (TM)	FSF	n.a. est. \$250-\$300	Good quality "Franklin" fireplace. (RAIN, November 1976)
Sears, Roebuck & Co.	Freestanding Franklin Fireplaces	FSF	\$186-\$237	Generally poorer quality than other "Franklin" types

Table 9.5.5, continued
Woodstove Manufacturers Guide

Manufacturer or Distributor	Brand Name	Type Stove	Cost	Remarks
Washington Stove Works P.O.Box 687 Everett WA 98201	Olympic (TM)	FSF	n.a. est. \$250- \$300	WSW is noted for quality construction.
Washington Stove Works	Artic (TM) 20 25 30	CS CS CS	\$105 \$140 \$175	Good quality castiron stoves. Expect high efficiency from tight construction. (RAIN, 1976)
Martin Industries 1604 17th Av., S.W. Sheffield, AL 35660	King 624 628	CS CS	\$125 \$140	Medium quality. (RAIN, 1976)
Atlanta Stove Works Atlanta, GA 30307	Atlanta 27	CS	\$110	Medium quality, poor fitting assembly. (RAIN, 1976)
Martin Industries	Ashley 25 HF 23 HF	CCS CCS	est. \$250	Fair quality airtight heater with automatic thermostat. Combined sheet steel and cast iron construction. (RAIN, 1976)
Kristia Associates P.O. Box 1461 Portland, ME 04101	Jøtul 118 602	CCS CCS	est. \$450 \$300	Finest quality enameled cast iron stoves, giving most efficient use of wood.
Portland Stove Foundry 57 Kennebec Portland, ME 0401	Lange 6203 BR 6303 6302A	CCS CCS CCS	\$295 \$315 \$375	Very good quality from Denmark--similar design to Jøtul and Trolle.
Scandinavian Stoves Box 72 Alstead, NH 03602	Trolle 102 105 118	CCS CCS CCS	\$199 \$245 \$400	Slightly cheaper enameled cast iron. Very good quality; expect same efficiency as Jøtul.
Riteway Mfg. Co. P.O.Box 6 Harrisonburg, VA 22801	LF 30 (furnace) LB 30 (boiler)	CCS CCS	\$1115 \$3088	Full size central heating furnaces and boilers. Oil or gas burners are also available as back-up units. Domestic hot water coils are also optional.

Table 9.5.5, continued
Woodstove Manufacturers Guide

Manufacturer or Distributor	Brand Name	Type Stove	Cost	Remarks
Riteway Mfg. Co. P.O. Box 6' Harrisonburg, VA 22801	Riteway 2000	CCS	\$295	Plate steel construction with thermostatically controlled draft. These are the best quality domestic stoves.
Riteway Mfg. Co.	LF 30 (furnace)	CCS	\$1115	Full size central heating furnaces and boilers. Oil or gas burners are also available as back-up units. Domestic hot water coils are also optional.

The above list of manufacturers is not meant to be exhaustive, but rather it is representative of what is available. Below is a list of manufacturers or distributors which is for the most part complete.

Table 9.5.6

Woodstove Manufacturers

Autocrat Corporation
New Athens, IL 62264

Atlantic Stove Works
Atlanta, GA 30307

Bellway Mfg. Co.
Grafton, VT. 05146

Birmingham Stove &
Range Co.
Box 3593
Birmingham, AL 35202

Brown Stove Works
Cleveland, TN 37311

C & T Distributing
Box 70224
Seattle, WA 98107

Calcinator Corp.
Bay City, MI 48706

Fatsco
251 N. Fair Av.
Benton Harbor, MI 49022

Enamel & Heating Products, Ltd.
Suite 1002, 1107 Broadway
New York, NY 10010

The Firebox Co.
P.O. Box 1
Richmond, MA 02154

Fire-View Distributors
P.O. Box 370
Rogue River, OR 97537

Table 9.5.6, continued
Woodstove Manufacturers

Fisher Stove
2103 - 196th S.W.
Lynnwood, WA 98036

Forest Fuels, Inc.
7 Main Street
Keene, NH 03431

Gardenway Research
Charlotte, VT 05445

Heatilator Fireplace
Div. of Vega Industries
Mt. Pleasant, IA 52641

Kingli Brothers
8056 Winthrope
Oakland, CA
Kris
Kristia Associates
P.O. Box 1461
Portland, ME 04104

Len-Jay Furnace Co.
Underwood, MN 56586

Locke Stove Co.
114 W. 11th St.
Kansas city, MO 64105

Longwood Furnace Grp.
Gallatin, MO 64640

Majestic Company
Hunnington, IN 46750

Malm Fireplaces, Inc.
368 Yolanda Av.
Santa Rosa, CA 95404

Marcade Winwood
P.O. Box 11382
Knoxville, TN 37919

Martin Industries
1604 - 17th Av., S.W.
Sheffield, AL 35660

Merry Music Box
10 McKown St.
Boothbay, ME 04538

Modern Machine & Welding
2307 Hwy. #2 West
Grand Rapids, MN 55744

Monarch Range Co.
Beverdam, WI 53916

Portland Stove Foundry
57 Kennebec
Portland, ME 04101

Riteway Mfg. Co.
P.O. Box 6
Harrisonburg, VA 22801

Scandinavian Stoves, Inc.
Box 72
Alstead, NH 03602

Shenandoah Mfg. Co., Inc.
P.O. Box 839
Harrisonburg, VA 22801

Stone Castle, Inc.
6160 90th Av., S.E.
Mercer Is., WA 98040

Superior Fireplace Co.
4325 Artesia Av..
Fullerton, CA 92633
601 North Point Rd.
Baltimore MD 21237

Torrid Mfg. Co., Inc.
1248 Poplar Place South
Seattle, WA 98114

9.2.1.2 Pyrolysis

Pyrolysis is a thermochemical process in which organic material is heated to high temperatures (1000°-2000°F) in a controlled or oxygen-free environment (Crentz, 1973; Dugas, 1973). The principal products of this thermal reaction are a low BTU gas consisting mostly of carbon monoxide, hydrogen, and a solid char material. Charcoal is also produced by this process.

The process of pyrolysis has been known for some time; it has been applied to other hydrocarbon sources such as coal for gasification and to natural gas for methanol and ammonia production. During World War II more than 9,000 automobiles in Europe were powered by "wood gas" pyrolysis units (Reed, 1973).

The low BTU gas is combustible, but it contains considerable tars, is deadly poisonous, and will barely sustain combustion in an internal combustion engine. It can, however, be easily converted to a liquid fuel, methanol, by reacting the gasses with a catalyst.

Methanol is a versatile fuel for transportation purposes. It has a fuel value of 9,600 BTU per pound, and it can be mixed up to 30% with other fuels e.g., gasoline, and burned with no engine modifications. It replaces lead as an additive to gasoline. Methanol can also be used solely as fuel for an engine with some slight modifications to compression ratio and carburetion. It has an octane rating of 106 and is frequently used as a racing fuel, burning cleaner and yielding higher efficiency than gasoline (Reed, 1973).

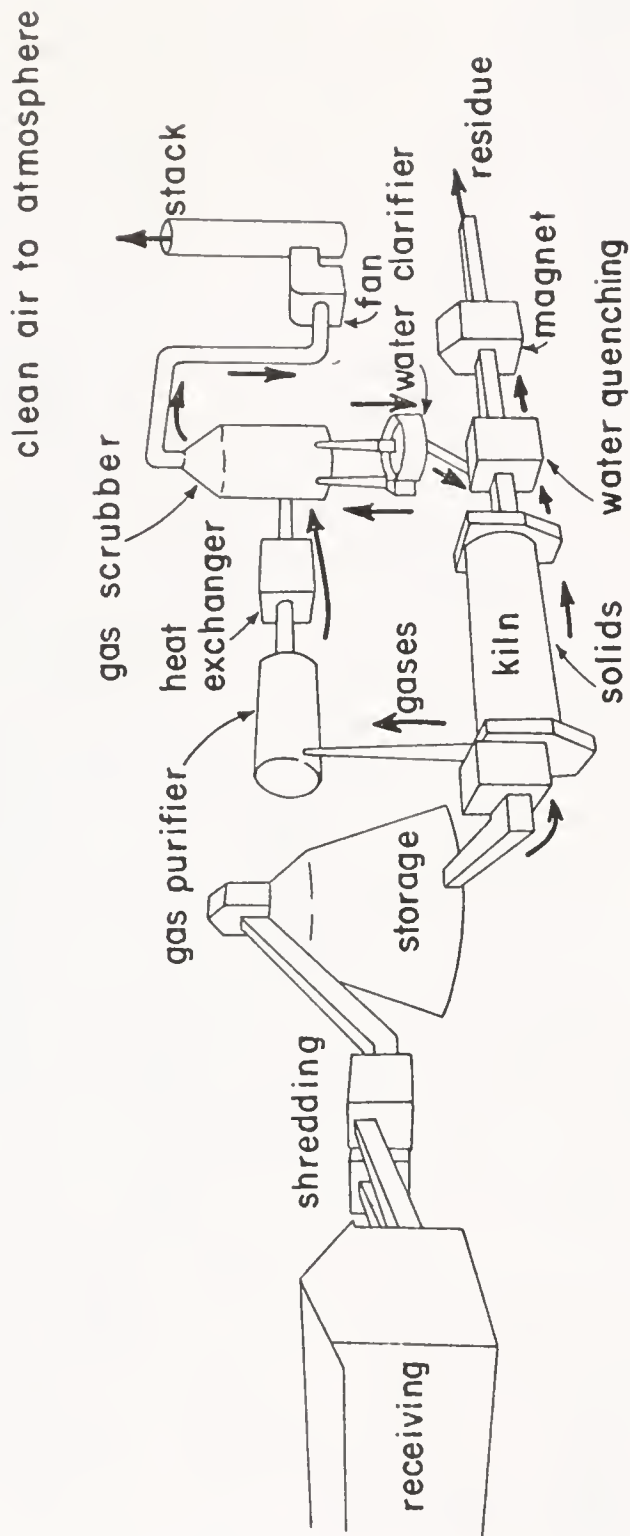


Figure 9.10
LANDGARD Solid Waste Disposal System

Source: reprinted from Kash, et al, 1975

9.2.1.2.1 The Monsanto Company has developed a patented process pyrolysis unit. The Monsanto LANGUARD system is designed for total recovery of solid waste. A thirty-five (35) tons per day pilot plant in St. Louis County has successfully demonstrated the feasibility of the system. A full scale unit is presently under construction in Baltimore, Maryland. The Baltimore plant will have a maximum daily loading capacity of 1000 tons of solid waste.

Figure 9.10 illustrates the LANGUARD system. Shredded solid waste are pyrolyzed at a maximum temperature of 1300°F. The resulting product of this process is a very low-BTU gas. The 100 BTU/cf gas is burned in a gas purifier to generate steam. The products expected daily from the system are as follows: 80 tons of carbon, char and ash; 70 tons of ferrous metals; 170 tons of glassy aggregate; and 4.3 million tons of steam for district heating. The steam is sold to Baltimore Gas and Electric. The ash will either be landfilled or mixed with sewage sludge for fertilizer, and the glass and metal are saleable (Kash, et al., 1975).

9.2.1.2.2 The Garret Pyrolysis system, like the LANGUARD, is a total resource recovery process. The Garret system differs mainly in that its principal fuel output is oil and has the trade name Garboil. Figure 9.11 from Kash (1975) gives a diagrammatic description of the process. A four ton per day pilot plant in LaVerne, California, has substantiated the process feasibility, and a 200 ton per day facility is under construction for the cities of Escondido and San Marcos, California.

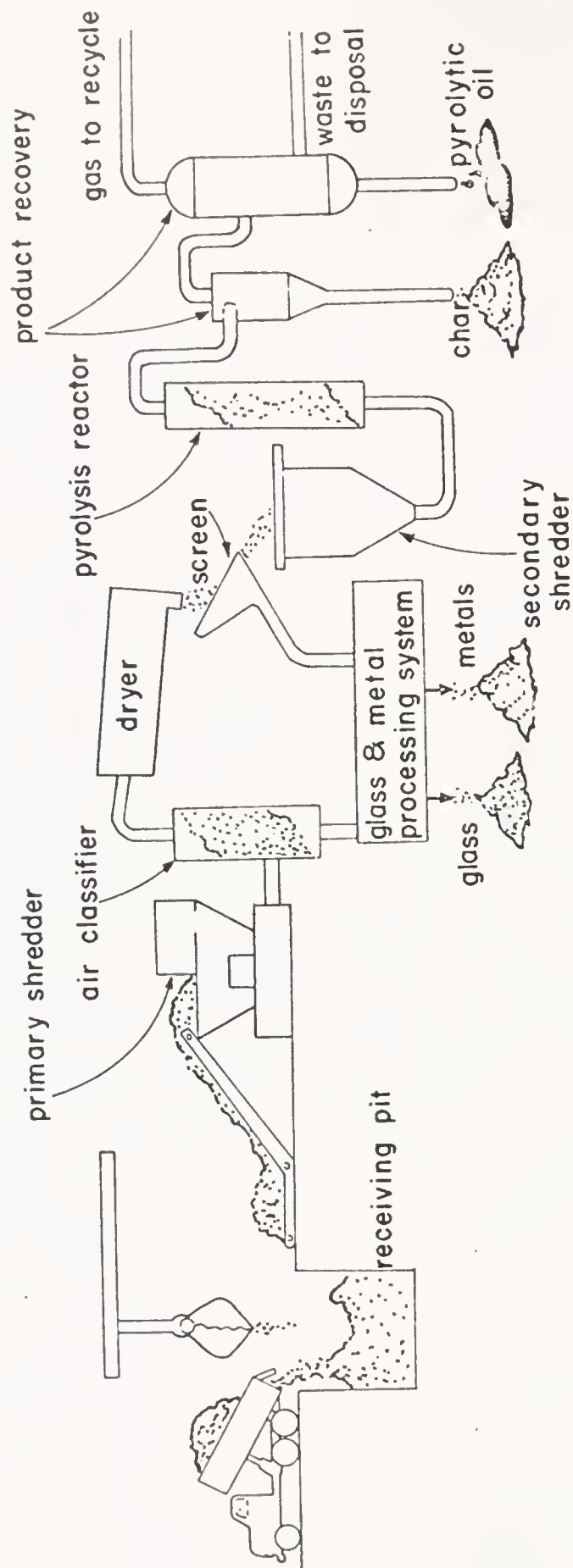


Figure 9.11

Garrett Pyrolysis Process

Source: reprinted from Kash et al, 1975

San Diego Gas and Electric Company will be the purchaser of the oil produced at the facility.

The Garret process utilizes a two-stage shredding process. First, raw refuse is shredded into one to two inch particles. These particles are then dried and air-classified to separate metals, glass, and other inorganics out of the feed substrate. Next, a secondary shredder reduces the first stage substrate to particles of a one-eighth inch (1/8") maximum size before they enter the pyrolysis reactor.

Within the reactor, the dry organic material is heated in the range of 930°F to 1650°F. This yields oil, gas, and char. All the gas and one-third of the char are used to fuel the drier and the pyrolytic reactor.

Garboil, although combustible for power plant use, differs chemically from petroleum crude oil. Because of its high viscosity, Garboil must be preheated to 160°F so that it can be pumped.

The typical products of the Garret process are as follows:

- oil: 40% by weight at 10,500 BTU/lb.
- char: 20% by weight at 9,000 BTU/lb.
- gas: 27% by weight at 55 BTU/cf.
- water: 13% by weight.

These figures have been verified on the four ton per day pilot plant (Mallan and Titlow, 1976).

9.2.1.2.3 The PUROX (TM) system by the Union Carbide Company is an "economically attractive and environmentally sound system for the disposal of municipal solid waste and the recovery of resources from solid waste" (Donnegan, 1976).

Presently a 200 ton per day facility is going through shakedown testing at South Charleston, West Virginia. The facility is currently in Phase II of a three phase testing program. It has already been established that the system will accomplish its prime objective, i.e. it provides a gas which can conveniently substitute for coal, oil or natural gas in industrial or electricity boilers.

The PUROX system employs pure oxygen to assist in the pyrolysis of the combustible portion of the refuse. The resulting gas is primarily carbon monoxide and hydrogen.

Table 9.6.1
Gas Fuel Analysis Typical for the
PUROX System

Gas	% Volume
CO	40-50
H ₂	25-30
CO ₂	10-20
CH ₄	3-6
Higher Hydrocarbons	0.5-2
Heating Value: 270-320 BTU/cf	

Source: Donnegan, 1976

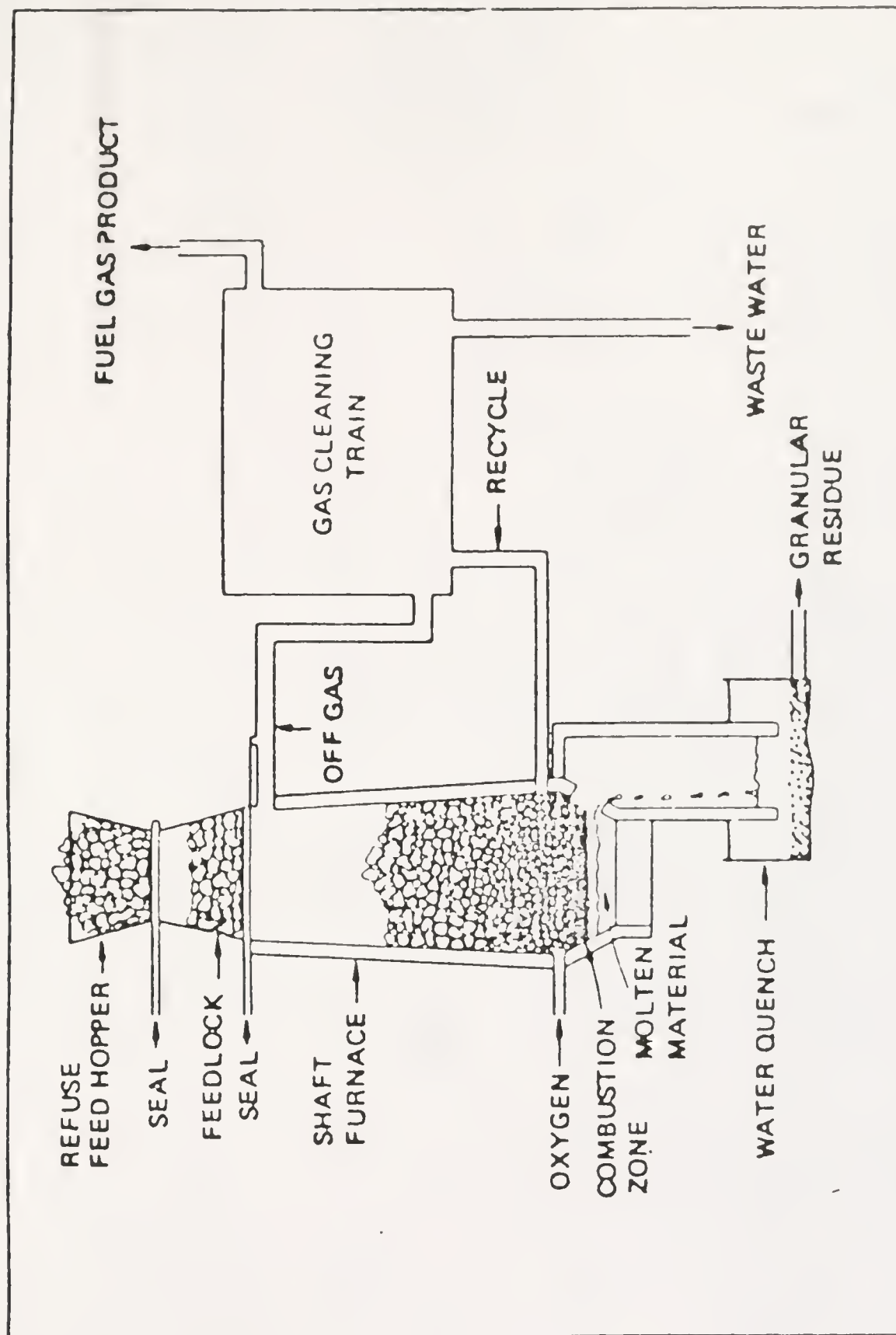


Figure 9.12
Purox Oxygen
Refuse Conversion Process

UNION CARBIDE CORPORATION

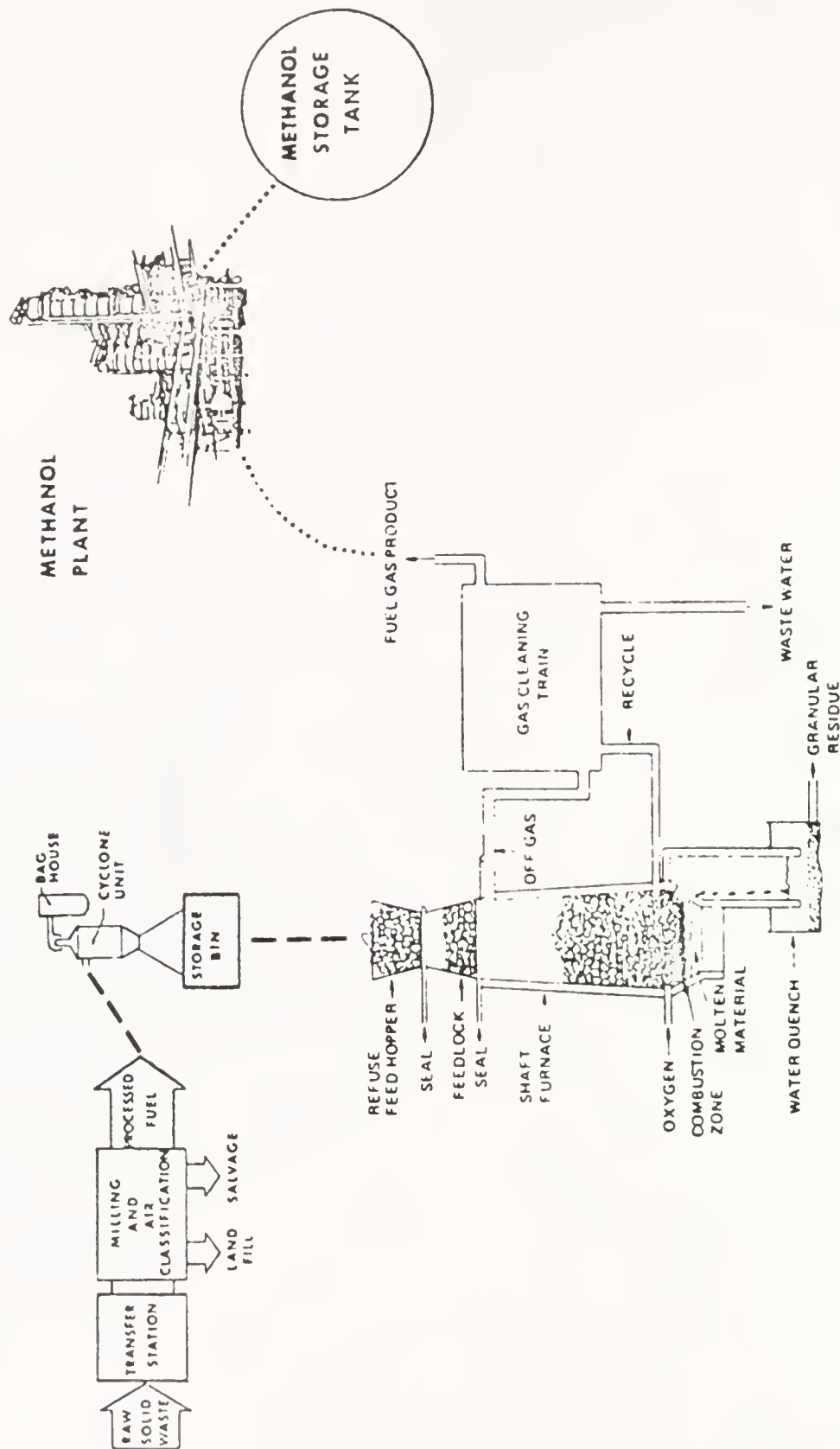
Source: reprinted from Donnegan, 1976

Figure 9.13

Purox Process Adapted to Methanol Production

PROCESSED SOLID WASTE PYROLYSIS -- OXIDATION

METHANOL PRODUCTION



In a planned application for the City of Seattle, the PUROX system will be used to produce either methanol and/or ammonia. Methanol is created by catalytic conversion of the gas.



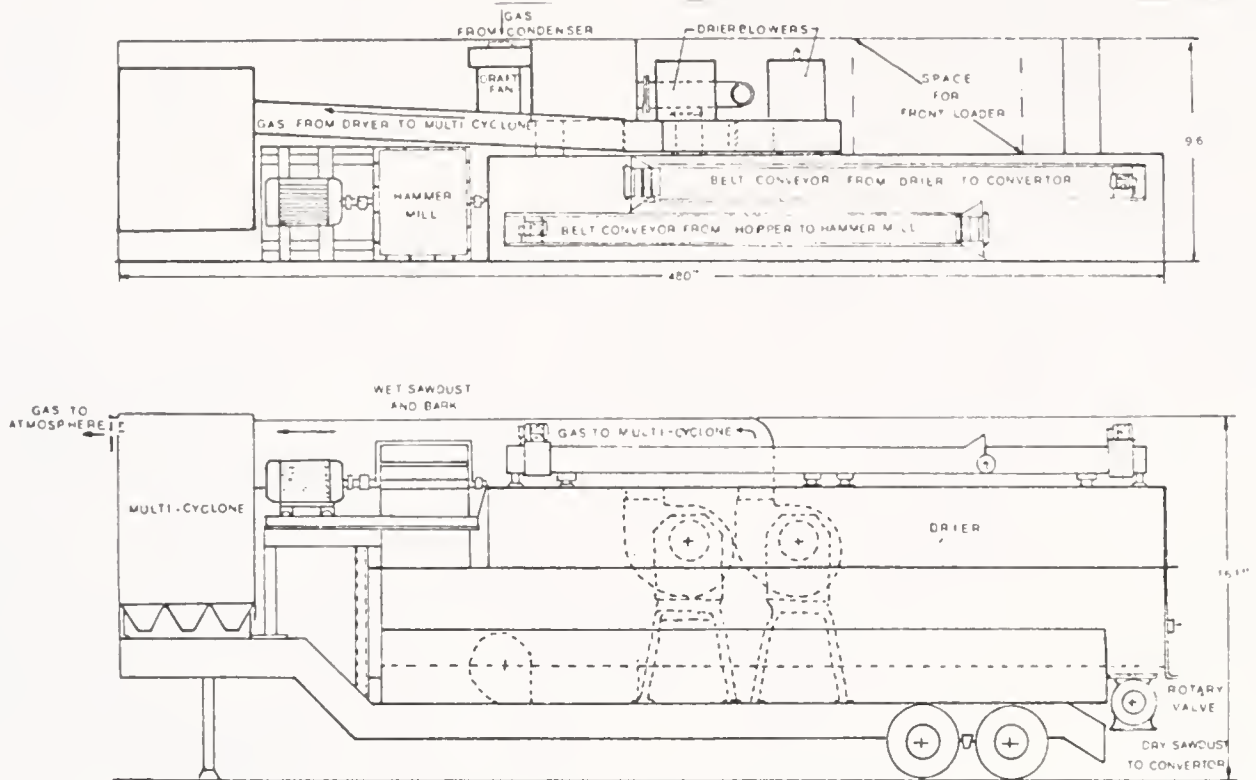
Ammonia is synthesized using a similar process, but liquid nitrogen is used to scrub out all the gases except hydrogen. This addition of nitrogen not only scrubs out the unnecessary gases, but it also produces a new synthesis gas: $\text{N}_2 + \text{H}_2$. This synthesis gas then enters an ammonia-reaction stage and is converted to anhydrous ammonia plus a purge stream which is burned for process heat (City of Seattle, 1975).

9.2.1.2.4 A mobile pyrolytic converter has been developed at the Engineering Experiment Station at Georgia Tech in Atlanta, Georgia, where a 50 ton per day demonstration plant has been built and operated. This process produces a solid char fuel which is mixed with fuel oil to yield a heat value of 11,000-13,000 BTU per pound. This black slurry can then be used to fire oil burners or even further mixed with coal to reduce sulphur problems in coal-fired steam plants (Pollard, 1976). This type of system offers great benefits where resources are dispersed, as is the case with many crop and forest residues (Tatom, 1975).

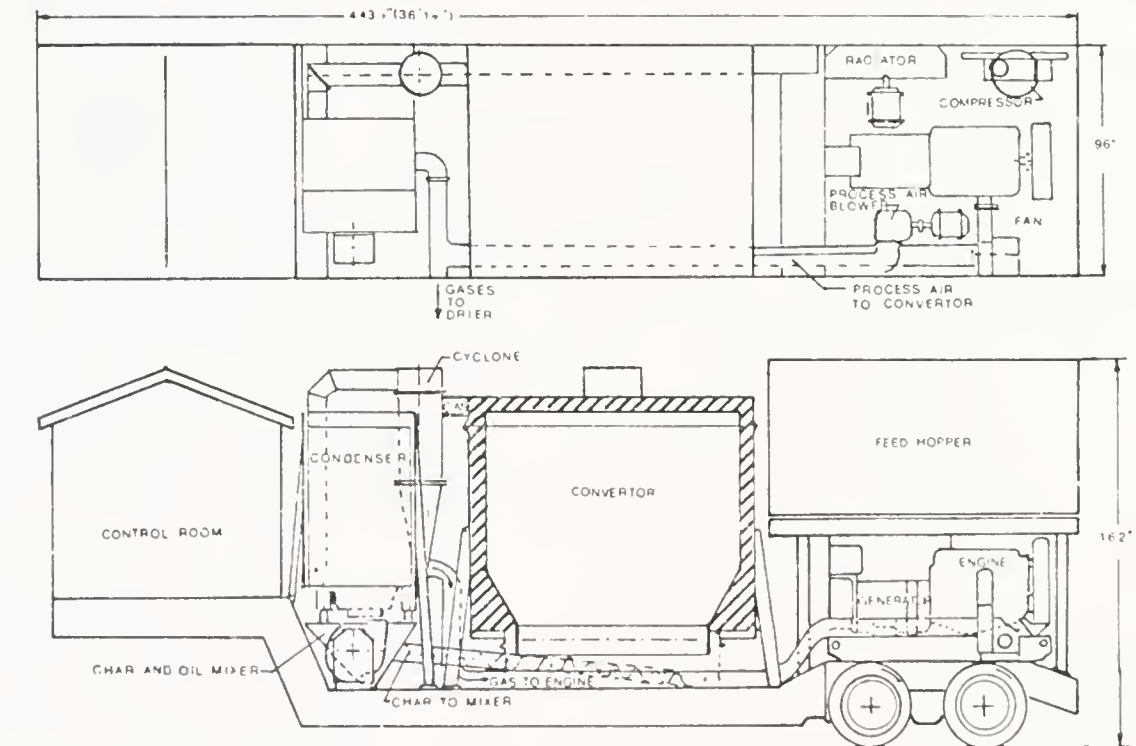
Pyrolysis technologies are very well developed: there are several commercial units available in addition to the mobile unit at Georgia Tech. Some of these are listed in Table 9.6.

Figure 9.14

Tech-Air Mobile Pyrolysis System



Plan and elevation views of drier trailer.



Plan and elevation views of converter trailer.

Table 9.6.2

Comparison of Commercial and Existing Prototype Units
for Pyrolysis

Name, Company or Process	Primary Resource Used	Maximum Daily Loading	Energy and/or By-Products	Process Efficiency*	Reference
Monsanto- Langard [®]	Solid Waste	1000 tons** 35 ton prototype	Char (solid fuel) and process steam	71.0%	Kash (1975)
Garret	Solid Waste	200 ton** 4 ton prototype	oil, gas (CO+H ₂) and char	45.7%	Kash (1975)
Union Carbide Purox [®]	Solid Waste	2000 ton** 340 ton (Seattle)** 200 ton	gas methanol or ammonia gas	62.7%	Donnegan (1976) Sheehan (1974) Donnegan (1976)
Tech-Air Corp. (Georgia Tech) EES system (mobile unit)	Wood residue and crop residue	25 ton proto. 50 ton proto. 200 ton**	char oil and gas	68.0%	Tatom (1974)

* Process Efficiency = $\frac{\text{BTU value of energy output}}{\text{BTU value per pound of dry matter of the resource + other process energy inputs}}$

**Full scale unit planned or under construction

9.2.1.3 Hydrogenation

Hydrogenation is used to describe two processes which involve the reaction of carbonaceous material with hydrogen-rich gases at modest temperatures -- usually in the presence of a catalyst -- to form hydrocarbon gases and liquids. (Hammond, 1976)

One of these processes -- hydrogenation -- has been developed by the Bureau of Mines (Fu, 1974) to convert bovine manure into a heavy, paraffinil oil with a low sulphur content (less than .4%) and a heat value of 14,000 to 16,000 BTU per pound (Ifeadi, 1975).

The other process is hydrogasification, fashioned after the Hyprane process originally developed by the Bureau of Mines for upgrading coal gas to pipeline quality (Ifeadi, 1975). Neither of these technologies seem well enough developed for practical implementation.

9.2.2 Microbiological

The advantage of the microbiological approach is that it can handle material with high moisture content and, in fact, requires additional water in some cases since the processes take place in an aqueous slurry. This, of course, makes some resource materials more adaptable for conversion by this process than others. Materials with 50-90% water content are shown in Table 9.2 (page 4).

These resources, aquatic plants, sewage and manure, are best utilized by the fermentation processes. Combustion of these resources is more efficient by dry weight of volatile matter, but there is a serious constraint to achieving a combustible fraction. Because of the high moisture content of these materials, they must either be dried using fuel or dried ambiently. Ambient drying requires large areas; it is dependent on climatic conditions; it is seldom effective at removing enough moisture. Fuel consumption for drying obviously lowers the process efficiency since fuel consumed in the process must be subtracted from the net usable output.

Microbiological processes demonstrate a distinct advantage over thermochemical processes. This is specifically related to the relative value of residues from the two systems.

With the microbiological processes, the residue retains the nitrogen portion of the biomass or organic residue. This soil conditioner has a measurable fertilizer value which can be quantified in terms of its replacement value when related to commercial chemical fertilizers.

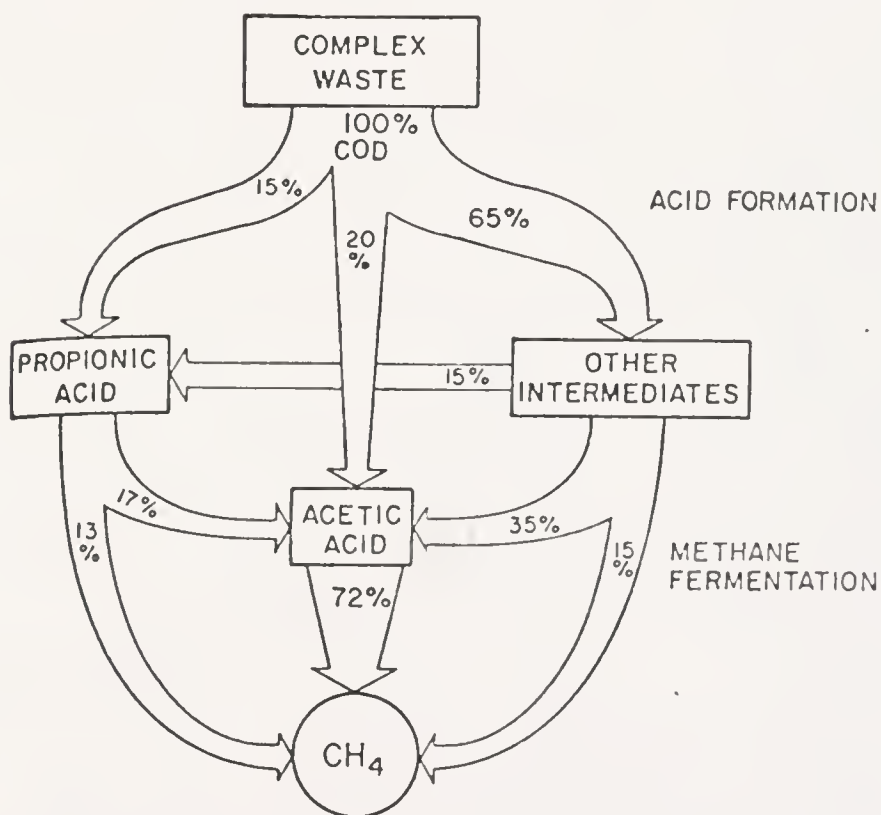
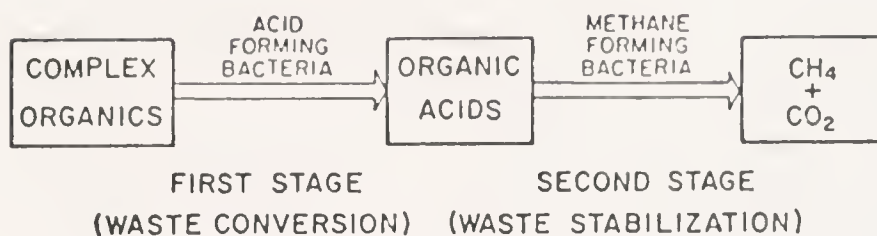
The quantity of the fertilizer value can be expressed in both economic and energetic terms. Economically, the value is the dollar amount of the pounds of nitrogen in the residue (Eco-tope Group, 1975). Energetically, the value is expressed as the energy savings from not consuming fossil fuels to chemically producing nitrogen fertilizer.

The thermochemical processes yield an ash residue. While this residue is important as a mineral (potash) supplement to fertilizer, it is relatively ineffective in replenishing biomass or in sustaining a yield for renewing the resource.

The microbiological processes are part of a total ecological cycle. The concept of "renewable energy" mandates a sustained yield strategy. Where there are decision points between processes, this factor should be considered most thoroughly.

Figure 9.15

The Methane Fermentation Process



Source: reprinted from McCarty, 1964

9.2.2.1 Methane fermentation

Methane fermentation (anaerobic digestion) is a process that involves the decomposition of organic matter in an oxygen-deficient environment. The chemistry of anaerobic digestion is not well understood. The anaerobic process of methane fermentation is widely used in modern sewage treatment plants, and the overall understanding of the methanogenic process has been developed over the past fifty years. It has reached a stage of reliability and this fermentation process is done with a great deal of certainty.

Methane fermentation is a simple technology requiring a reactor tank, mixing equipment, associated pipes, pumps, and controls to transfer the organic material. Ideal conditions include the factor of reactor size and retention time versus gas production and degradation. Heat must be added to keep the bacteria warm. The process requires low grade heat and is usually operated at 36°C (95°F), although it can be successfully operated between a range of 5°C (40°F) and 60°C (140°F). Increased heating accelerates the bacterial activity, reducing the retention time and thus the tank reactor size.

This anaerobic process takes place in three stages. First, the proteins, carbohydrates and fats are dissolved. The second stage is acidification, where non-methanogenic bacteria convert these soluble organics into organic acids. In the third and final step, the methane-forming bacteria reduce these organic acids and other oxidized compounds to methane (CH_4) and carbon

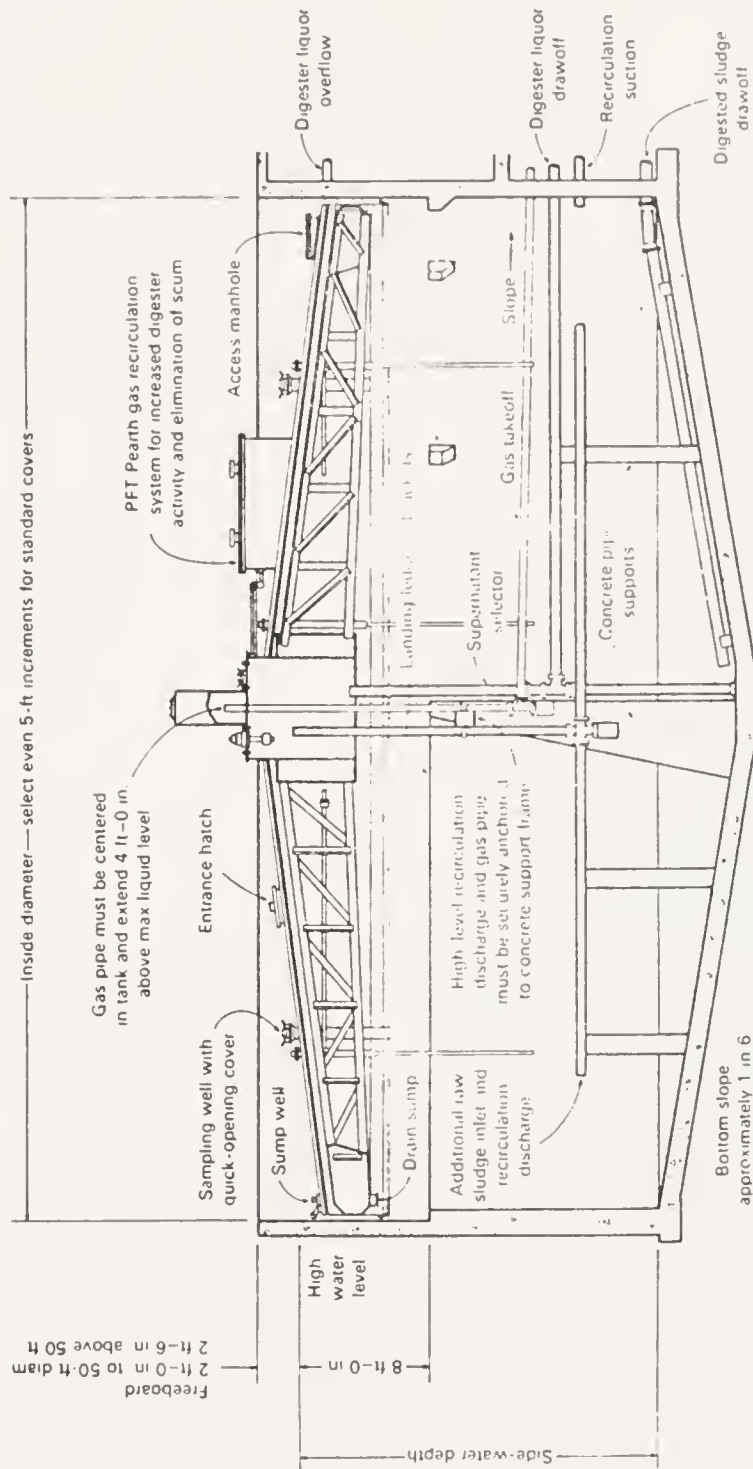


Figure 9.16

Cross Section Through A Typical Standard Rate Digester (Fermenter)
Tank for Treatment of Municipal Sewage Solids

Source: reprinted from Metcalf and Eddy, Inc., 1972

dioxide (CO_2) as well as other trace gases: hydrogen sulfide (H_2S), nitrogen (N_2), and others.

Biogas is about 60-70% methane and has a heat value of 600-700 BTU/cu.ft. Natural gas is almost pure methane with a value of about 1000 BTU/cu.ft. The conversion efficiency for the process varies with the degradation of the volatile material from 40-60%. This degradation also transforms organic nitrogen into ammoniated nitrogen to yield a more stable residue for application as fertilizer or soil conditioner.

Methane fermentation has been highly developed for sewage treatment and this technology is directly transferable to animal manures (Tainganides, 1963; Hart, 1963; Teitjen, 1975; Jewell, 1976; Abeles, 1975). Work has been done more recently to utilize this process by combining solid waste with sewage (Klein, 1972; Kispert, 1974). Combinations of 80% solid wastes and 20% sewage have been demonstrated on a pilot scale to produce a 600 BTU/cf gas (Trezek, 1976).

Crop residue and food processing waste offer another opportunity for biogas production. At the University of Missouri, Rolla, the Chemical Engineering Department has researched, developed, and demonstrated a process which utilizes a slurry of ground crop waste (Pollard, 1976). Work at Montana State University will explore the breakdown of lignin -- a non-digestible plant material -- to further increase the efficiency of digestion of high cellulose material (Robbins, 1976). At Stanford, similar research on ligno-cellulosic separation is under way (McCarty, 1976). A breakthrough

in lignocellulosic degradation could broaden the applications of the biogas process to wood and forest residue and increase its efficiency as much as 50% (McCarty, 1976).

9.2.2.1.1 The Dynatech R and D Company of Cambridge, Massachusetts, under contract with the National Science Foundation (NSF), prepared a comprehensive computer model of a combination solid waste and sewage sludge digestion facility. Currently, a full scale demonstration project funded by the U.S. Energy Research and Development Administration is under construction at Pompano Beach, Florida. This demonstration project was the result of findings supported by the Dynatech Study.

The process of preparing solid waste for anaerobic fermentation is similar to other separating and shredding activities commonly employed in resource recovery operations. Solid waste is delivered to the facility by compactor trucks. The typical mix of solid waste reported for this study is given below:

Organic Matter	50%
Metal	8%
Glass	9%
Plastics	3%
Other Inorganics	5%
Water Content	25%

After mechanical separation, the remaining organic matter is shredded in preparation as feed to the fermentation process. The organic substrate is mixed with raw sewage sludge at a ratio of 0.05 sewage sludge to dry municipal solids. This ratio was derived from national figures for average per capita generation of solid waste published in a bulletin from the Center for Resource Recovery (1973).

The combined substrate of organic solid waste and sewage

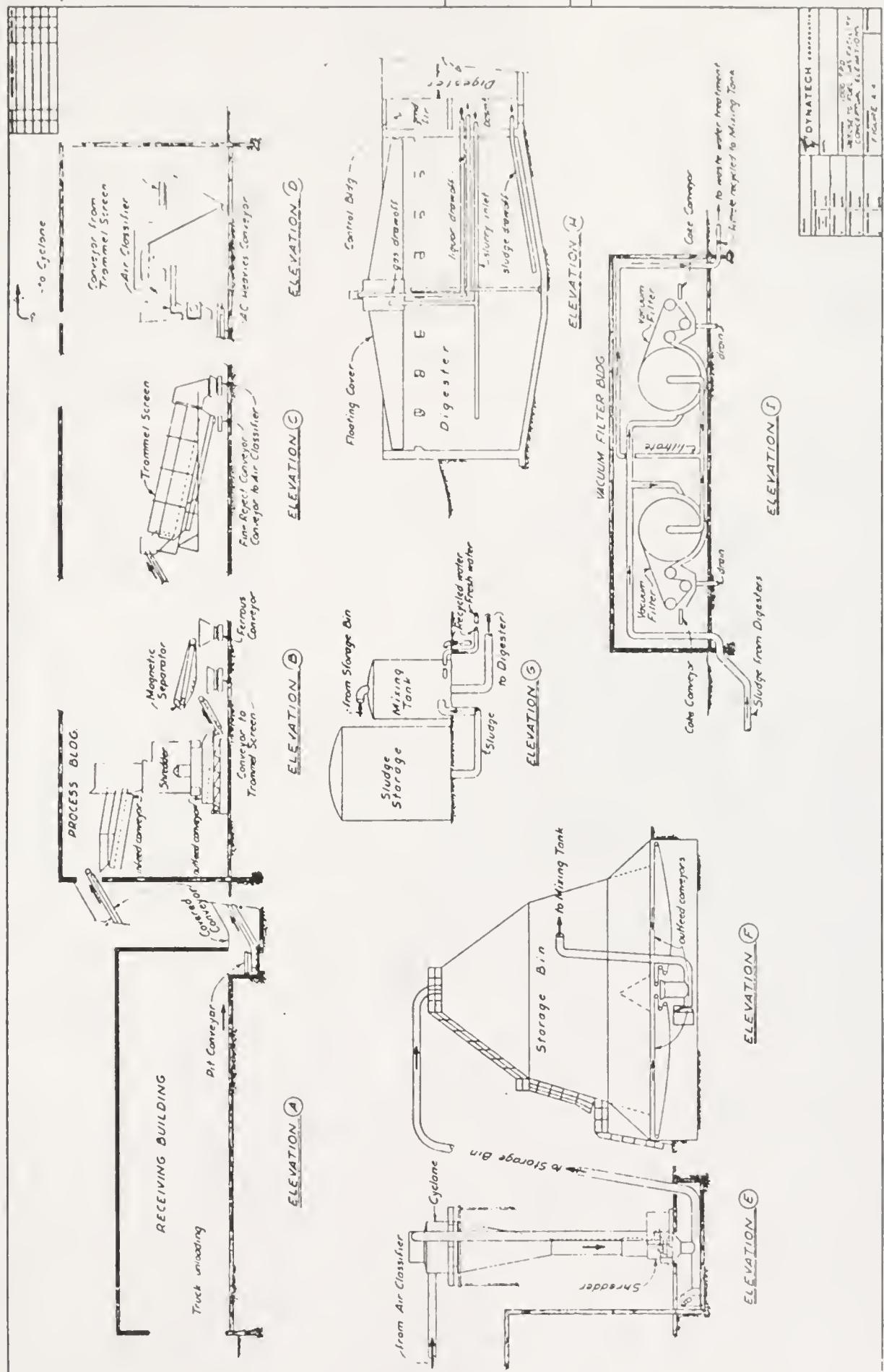


Figure 9.17
 Conceptual Elevation of a "1000 Ton Per Day Refuse to
 Fuel Gas Facility" by Dynatech R/D Company

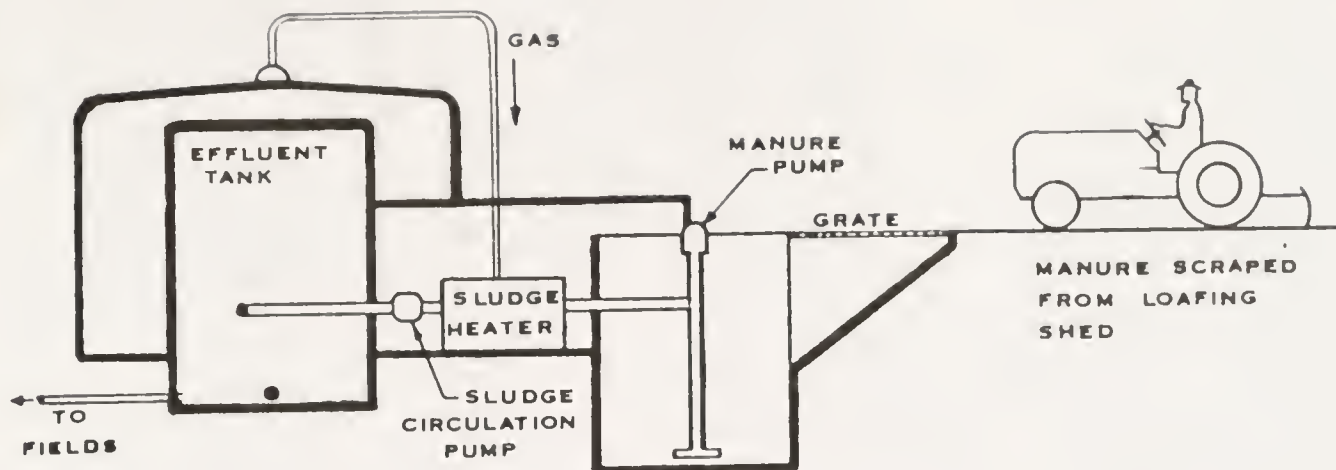
sludge is fed to two fermentation tanks or digestors where heat is maintained at 36°C (95°F), and the aqueous slurry is continuously stirred to encourage high-rate degradation, maximum gas production and minimum retention time.

The products of digestion yield two product streams. The gas stream consists of about equal parts of methane and carbon dioxide. The slurry stream is composed of both digested and undigested organic matter which is potentially a good fertilizer or soil conditioner.

The purpose of the process is to produce fuel gas of a similar quality to pipeline natural gas. This is accomplished by scrubbing the carbon dioxide and hydrogen sulfide gases out, leaving a pure methane gas. The methane must be further dried to be a marketable product.

A plant supplied by 1000 tons of solid waste per day was used to model the system. The amount of methane gas produced from such a facility would amount to a production of 3.7×10^6 cf/day. The process efficiency is 37.5% when the energy inputs to maintain the system have been accounted for.

9.2.2.1.2 A computer simulation has been constructed to evaluate a number of different parameters associated with a refuse flow rate of 1000 tons per day. There is, however, "a rather crude scaling routine" to allow evaluation of other flow rates, but these are limited to evaluation of front end parameters associated with refuse generation and are not applicable for analyzing the energy portion of the simulation.



SECTION A-A

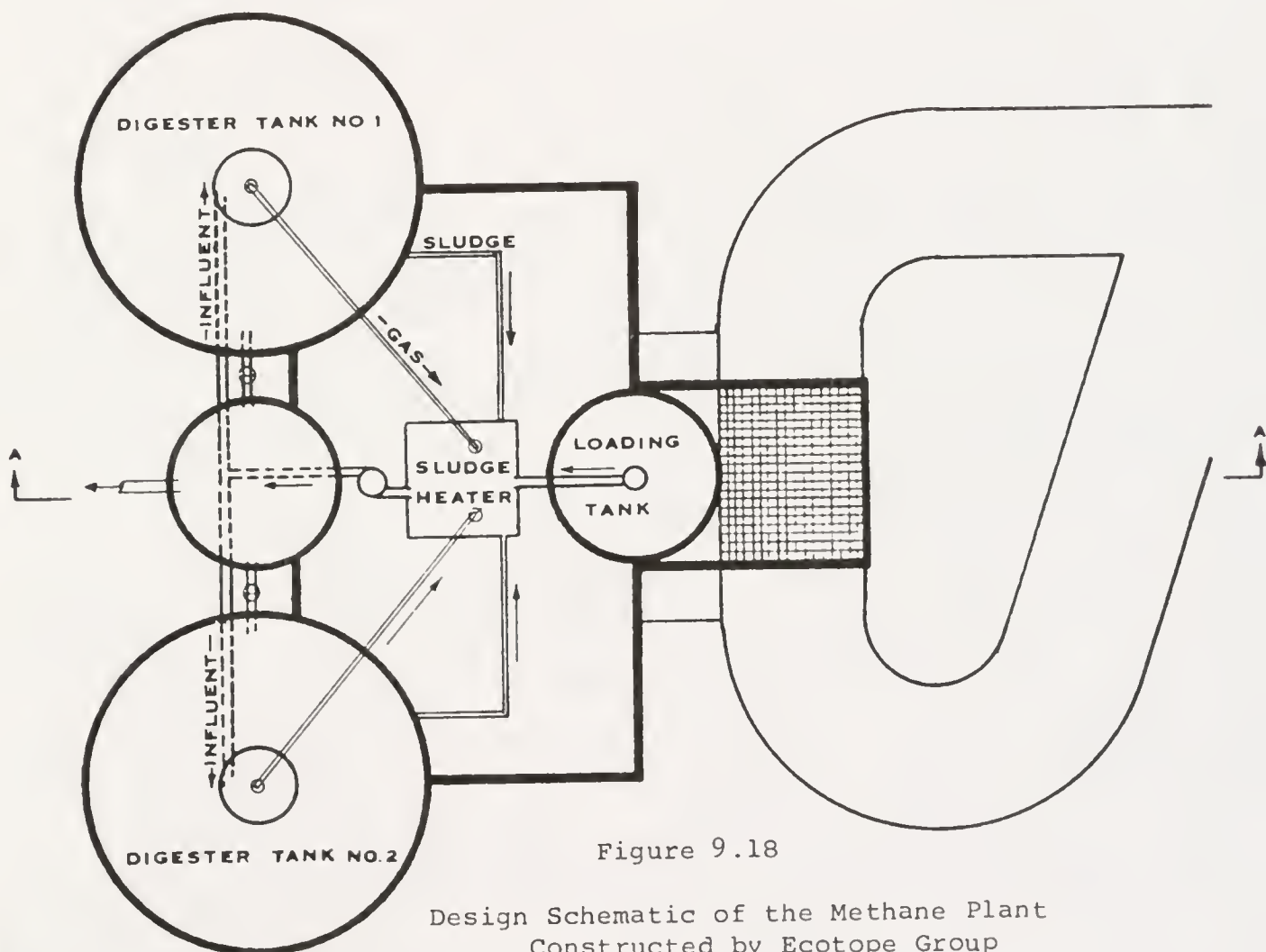


Figure 9.18

Design Schematic of the Methane Plant
 Constructed by Ecotope Group
 (1975) at the Monroe, WA,
 State Dairy Farm
 PLAN VIEW

The computer model is run in conjunction with laboratory scale fermentors which operate on various solid waste and sewage substrates. The simulation is meant to speed the analysis of variables which would take too long to evaluate in laboratory analysis.

The program output gives an energy balance, design criteria, mass flow, and a cost balance. Input variables include temperature, retention time, and solids loading rates.

9.2.2.1.3 Ecotope Group has constructed a 100,000 gallon methane facility at the State Reformatory Dairy Farm near Monroe, Washington. This facility has been operated in the period between January and May of 1975. Data from that period is sketchy and inconclusive, but gas production was adequate to indicate that the system would perform as good as, or better than predicted in The Process Feasibility Study (Ecotope Group, 1975).

This facility is designed and constructed to accept the residue from 300 animals in a confined dairy operation. The estimated output of the system is an average of about 8500 cf/day of biogas (approximately 5000 cf/methane).

An average of 3000 gallons of raw manure from the dairy loafing areas is to be scraped by tractor into a conditioning tank to be pumped into two 50,000 gallon reactors each day. A combination of sewage treatment and farm equipment technology has been integrated to construct the facility. The system is heated to 36°C (95°F), continuously stirred by recirculated gas, and is well-insulated for heat retention.

The system will resume operation in the spring of 1977 as a part of the Fuel from Animal Residue Program sponsored by the Division of Solar Energy, U.S. Energy Research and Development Administration. A final report will analyze the system and evaluate its cost effectiveness.

9.2.2.1.4 The Hypermion Sewage Treatment Plant in Los Angeles, California, is a good example of many existing methane fermentation units which have proven this technology over the past 40-50 years. Operating since the mid 1940's, this facility produces 5,000,000 cf/biogas (3,000,000 cf/methane) daily. Half of this gas is consumed in large internal combustion diesel engines to generate electricity and heat for operation of the facility. The remaining gas is piped to a gas turbine-fired electric utility next door to the sewage treatment plant.

In the 1950's, an additional facility to dry and market sludge cake was operated on the facility. Urbanization changed the land use from "truck farming" and destroyed the market for this product, but the facility remains.

The City of Milwaukee, Wisconsin, markets Malorganite^R as a commercial fertilizer throughout the country. This fertilizer is dried sewage cake from the sewage treatment facility in Milwaukee. This has proven to be highly sought after and a profitable product for the City of Milwaukee.

Performance of the Los Angeles Hypermion Treatment Facility can be considered typical for large city digestion systems. Decreases in net output can be expected with more severe climates, although proper insulation and heat exchanger apparatus can compensate for this factor. Smaller digestion

systems suffer from reduced economic scales. Methane fermenters have been widely used in small treatment plants ranging down in size to cities having populations of 3000 people. These plants can be largely self-sufficient in energy production and consumption. And, in most cases, net production is above and beyond internal requirements.

Proper design and integration of the facilities can be a great asset to many communities; this is especially true when combined to handle solid waste along with sludge.

9.2.2.1.5 Agriculture Energy Corporation (AEC) of Ludington, Michigan, has completed two farm methane fermentation facilities. A 350 head beef feedlot operation near Ludington has been in operation since 1974. A 150-head dairy operation near Rice Lake, Wisconsin, is their latest. AEC offers a complete "turnkey" service, wherein they install the system for the farmer.

The design used in this system is very simple, seemingly very effective, and inexpensive. In the 350-cow feedlot facility, the reactor tank is a trench which is 22 feet wide (6.7 meters) by 110 feet long (33.5 meters) by 6.8 feet to 8.8 feet deep (2.12.7 meters). The trench is lined with a plastic membrane or pond liner and is covered with a reinforced "Hypalon" rubber cover (Jewell, 1976).

Although no data is yet available on this system, it appears to be a very good system for small farm operations which cannot afford expensive sewage treatment hardware. Even though the system operates at lower temperatures and uses an unmixed "plug flow" design, it appears to be quite successful. Both AEC fermentation systems are fully automatic,

and they use gravity loading to eliminate pumps. Where pumps are required hydraulics are used to eliminate the danger of sparks from electrical equipment. Figure 9.19 from Jewell (1976) describes the system flow.

9.2.2.1.6 Hamilton Standard Laboratories of Windsor Locks, Connecticut, have developed a high-rate, thermophilic (temperature range 40⁰-60⁰C) reactor. This portable laboratory reactor has been used to evaluate performance of different animal substrates. Currently, Hamilton Standards is under contract with the Fuels from Biomass Program, Division of Solar Energy, U. S. ERDA to evaluate the feasibility of a large scale application of their process at the Kurer feedlot operated by Montford of Colorado in Greeley.

The Kurer lot is an open-air, dirt feedlot with a capacity of 65,000 head. Many problems have been encountered in trying to get high production using this particular substrate. Because there is a lot of dirt mixed with the manure and a certain amount of biodegradation takes place prior to the fermentation process, production of gas has been far less than expected. There is some reason to suspect certain antibiotics and other feed additives are inhibitors to the process.

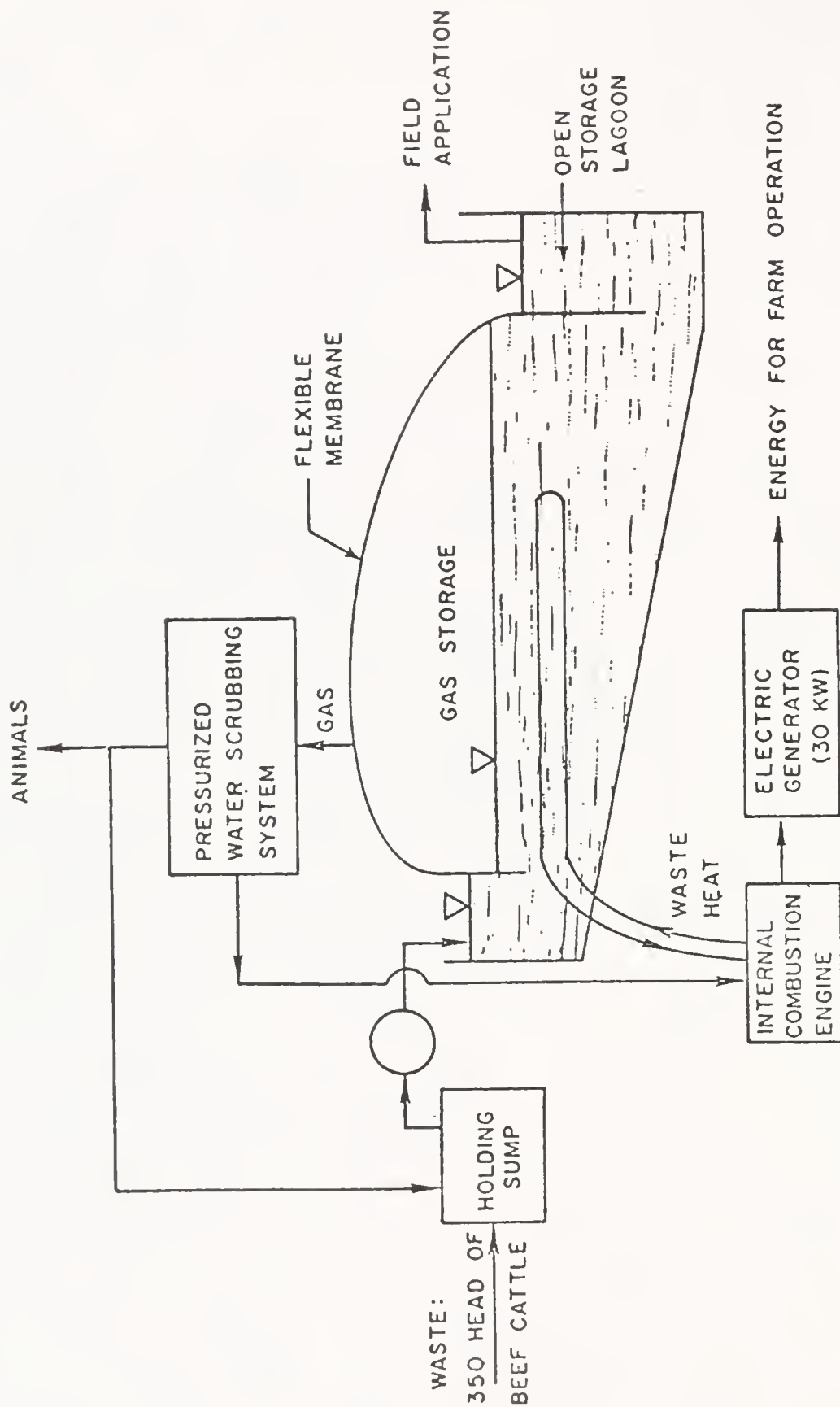


Figure 9.19

Sketch of layout of a full scale anaerobic fermentation unit in use on a 350 head beef feedlot in Michigan.

Source: reprinted from Jewell, 1976

Table 9.7

Comparison of Commercial and Existing Prototype Units
for Methane Fermentation

page 1 of 2 pages

Name, company or process	Primary Resource Used	Maximum Daily Loading	Energy and/or By-Products	Process Efficiency*	Reference
Dynatech R/D Company (simulation)	Solid waste and sewage sludge (0.05 ratio ss-sw)	1000 tons	methane gas and fertilizer	37.5%**	Kispert et al. (1974)
University of Illinois (simulation)	Solid waste and sewage sludge	1000 tons	methane gas, or steam, and fer- tilizer	35.9%	Quindry et al. (1976)
Ecotope Group Monroe Project Monroe, WA	Dairy animal manure	3000 gallons wet manure 1.5 tons/ dry weight (built system)	methane gas and fertilizer	36.6%	Ecotope Group (1975)
Hypermion Treatment Plant, Los Angeles, CA	Municipal sewage	approximately 1100 tons	methane gas, electricity and fertilizer (not used)	gas 50% electricity 19%	Personal Corres per RAIN bibliography

Table 9.7
Comparison of Commercial and Existing Prototype Units
for Methane Fermentation
Page 2

Name, company or process	Primary Resource Used	Maximum Daily Loading	Energy and/or By-Products	Process Efficiency*	Reference
Agriculture Energy, Inc. Ludington, MI	Steer manure	From 350- head feedlot est.	Methane gas, electricity and fertilizer	N/A	RAIN Magazine 1976
Hamilton Standards Laboratory	Animal Resi- dues--feedlot	1500 gallons prototype 156lb. dry matter	methane gas and fertilizer	N/A	

62

* Process Efficiency = $\frac{\text{BTU value of energy output}}{\text{BTU value per pound dry matter of the resource} + \text{other process energy inputs}}$

**Full scale unit planned or under construction

9.2.2.2 Alcohol Fermentation

This process, which utilizes yeast to convert sugar crops and grains into alcohol, is a major industry in this country. Alcoholic beverages from fermentation of fruits were in existence as early as 6000 B.C.; commercial breweries flourished in the time of the pharaohs in ancient Egypt.

The fermentation of sugars and starches by yeast yields ethyl alcohol, or ethanol-- "grain alcohol." Maximum alcohol production, in microbiological fermentation, has an upper limit of 14% by volume. Fuel and industrial grade ethanol of greater than 95% concentration by volume requires additional processing through heat for distillate separation of the alcohol from the mash.

Ethanol has a boiling point of 171°F (77°C) which allows it to be vaporized away from the fermented liquor, leaving most of the water behind. A historical evolution of stills is described in Figure 9.1.

Distillation will yield a 94-96% pure ethanol liquor. Purification beyond this point is economically senseless for most fuel and/or industrial processes.

Pure ethanol has a high heat value of 12,800 BTU/lb with a high octane number of 99. Like methanol, it can either be added to gasoline in a 10-30% solution without engine modification, or used wholly as a motor fuel with engine modifications in compression ratio and carburetion. In Europe, it has long been used as a motor fuel blended with gasoline (Gooding, 1967). Ethanol derived from sugar cane molasses is used industrially and as a motor fuel in Brazil. For 1980, the Brazilian goal is to raise the alcohol content of all gasoline to 10% (Calvin, 1976).

Ethanol is fermented biologically from carbohydrates: sugar, starch and cellulose.

Table 9.8
Carbohydrates Used in Ethanol Fermentation

Carbohydrate	Example
Sugars	Table sugar (sucrose) Milk sugar (lactose) Fruit sugar (fructose) Dextrose (grapes & glucose) Malt sugar (maltose)
Starches	Rice Corn Potatoes Wheat Barley
Cellulose	Wood Paper Straw Stalks Solid waste

Yeast fermentation occurs easiest with the sugars and with increasing difficulty and process with starches and especially with cellulose.

Ethanol from sugar crops has demonstrated the highest process efficiency since the enzymes are present and no special preparation or preliminary energy-consuming step is necessary, although certain nutrients are essential. The nutrients are usually present in the crops.

Ethanol from starch crops requires that a mash be formed and steamed under pressure. Sprouted grains -- malt, usually from barley -- provide a vital enzyme, diastase, which releases the sugars from the starch by splitting out the water molecules which entrap the sugars. Preparation of the malt extract is an age-old art practiced by brewmasters and dedicated monks. It is critical to the success of the entire process.

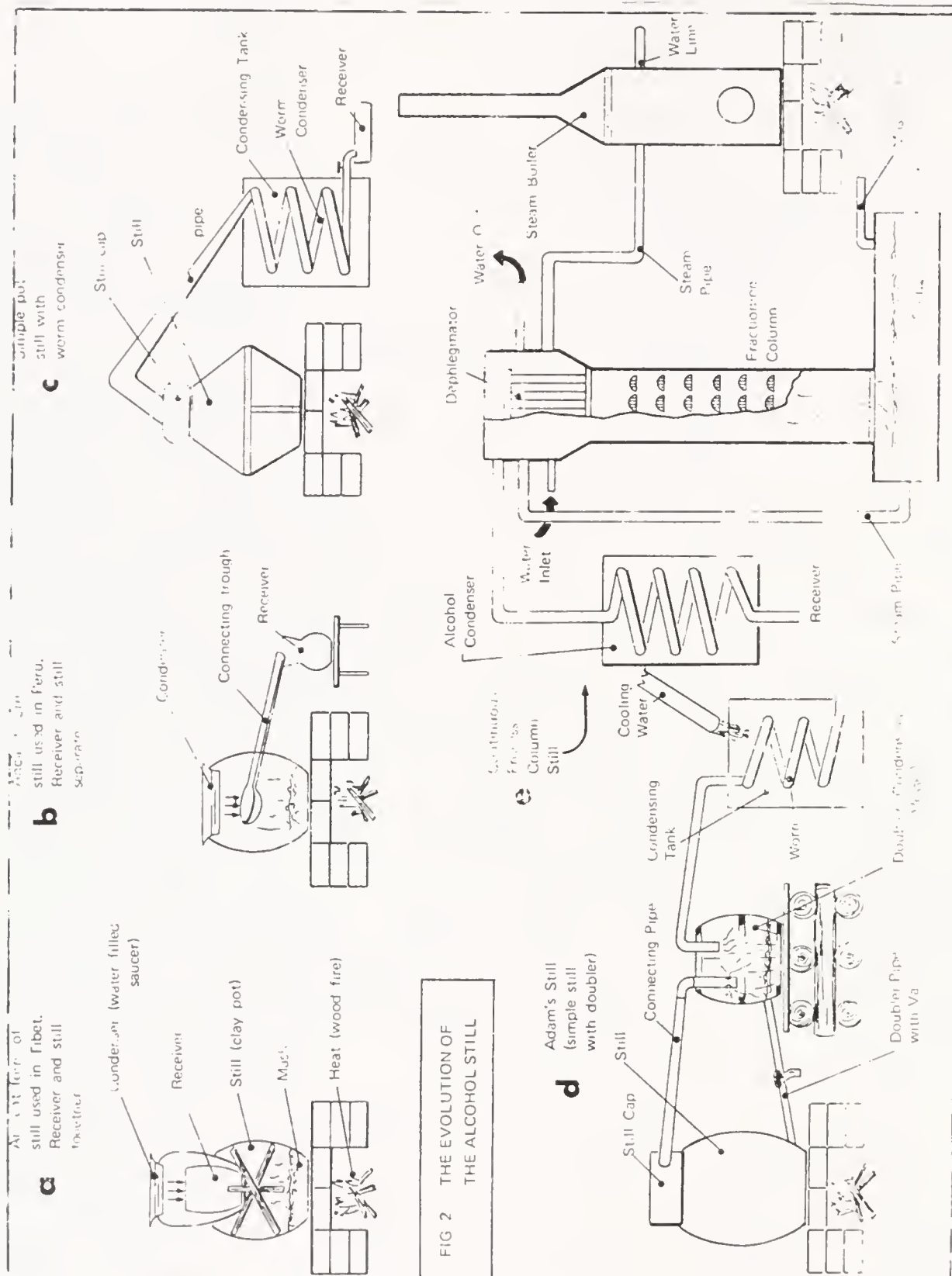


Figure 9.20

Table 9.9.1

Ethanol Yields from Various Farm Crops

SUGAR CROPS

Crop yields (except fruit) are from 1970 USDA agricultural statistics.
Fruit yields are for 1970, California Agricultural Extension Service.

Raw Material (lbs/bushel)	Average U.S. crop yield (tons/acre)	Fermentation Content	Yield of 99.5% Ethanol		Residual Solids (lbs/ton)
			Per Bushel Gallon	Per Acre Gallon	
<u>Main Crops</u>					
Sugar Cane	41.1	11.0%	--	15 623	--
Molasses	23.7gallons	51.0	--	70 97	--
Sugar Beet	19.1	16.0	--	22 420	100
<u>Fruit Crops</u>					
Apples (48)	14.4	11.0	0.4	14 207	40
Apricots	5.2	10.4	--	14 71	46
Grapes	7.9	11.5	--	15 119	76
Peaches (48)	11.3	8.7	0.3	12 130	34
Pears (50)	6.8	8.9	0.3	11 78	58
Prunes, dry	2.3	55.0	--	72 166	152
Raisins, dry	2.4	62.0	--	81 195	166

Table 9.9.2

Ethanol Yields from Various Farm Crops
STARCH CROPS

Raw Material (lbs/bushel)	Average U.S. crop yield (tons/acre)	Fermentation Content	Yield of 99.5% Ethanol		Residual Solids (lbs/ton)
			Per Bushel Gallon	Per Ton Gallon	Per Acre Gallon
<u>Grains</u>					
Barley (48)	0.9	54.3%	1.9	79	71
Corn (56)	2.0	57.8	2.4	84	168
Sorghum (56)	1.4	54.5	2.2	80	111
Oats (32)	0.8	43.6	1.0	64	51
Rice (45)	2.3	54.6	1.8	80	183
Rye (56)	0.7	54.0	2.2	79	55
Wheat (60)	0.9	58.6	2.6	85	77
<u>Tubers & Roots</u>					
Carrots (55)	11.8	7.5	0.3	10	116
Jerusalem Artichokes (60)	9.0	15.2	0.6	20	180
Potatoes (60)	11.5	15.6	0.7	23	263
Sweetpotatoes (55)	5.2	23.3	0.9	34	178
					92

Source: Reprinted from Merrill and Aston, The Energy Primer, 1974

Acid hydrolysis was discovered in 1819 (Merrill, 1974). This process for converting cellulose into simple sugars allows the conversion of almost all biomass forms into alcohol. Only half of the sugar cane can be used with the regular fermentation process, but acid hydrolysis can double the ethanol production by allowing all of the plant to be used. This process is given through analysis by Meller (1969).

The most promising breakthrough for conversion of cellulose into fermentable sugars appears to be a process developed at the U. S. Army Laboratories at Natick, MA. Tichoderma viride is a clothes-destroying fungus discovered by the Quatermaster Corp. Because of its particularly big appetite for pistol belts in the South Pacific during World War II (Kaufman, 1974), a laboratory scale process has been developed and is being used at the Natick Lab. This process is based on mutant strains of T.viride developed for their ability to cause rot in wood and cellulose material. T.viride works by producing cellulase, an enzyme which acts on cellulose, to convert it to glucose syrup. This syrup can be used as a chemical feedstock when changed to pure glucose or converted to ethanol (Spano, 1976).

ENZYMATIC CONVERSION OF WASTE CELLULOSE

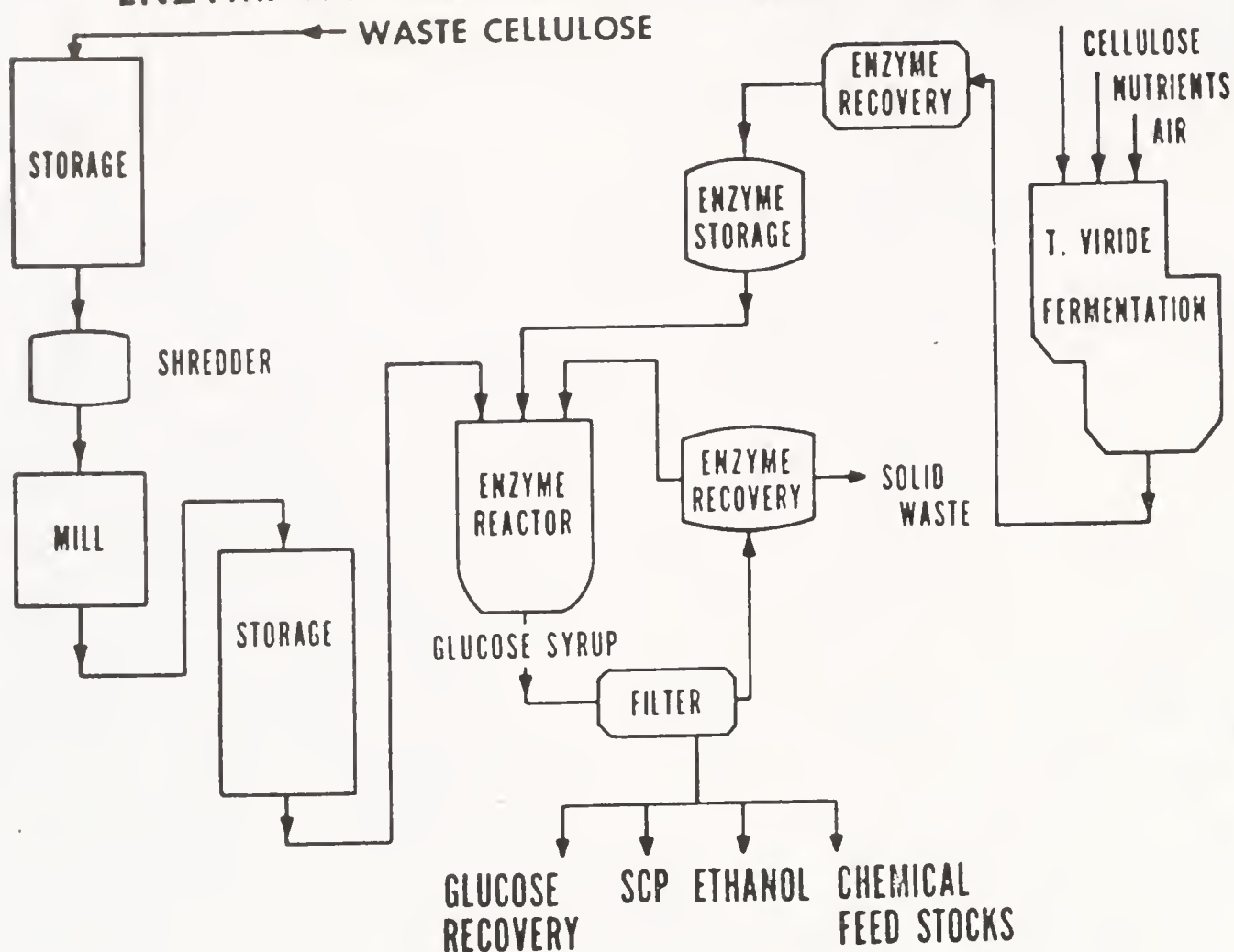


Figure 9.21

Process Developed at U.S. Army Laboratories, Natick, MA,
Utilizing the Fungus "Trichoderma Viride" to
Produce Cellulase Enzymes to Form Sugar
from Cellulose Materials

Source: reprinted from Andren and Nystrom, 1976

FIGURE 9.20

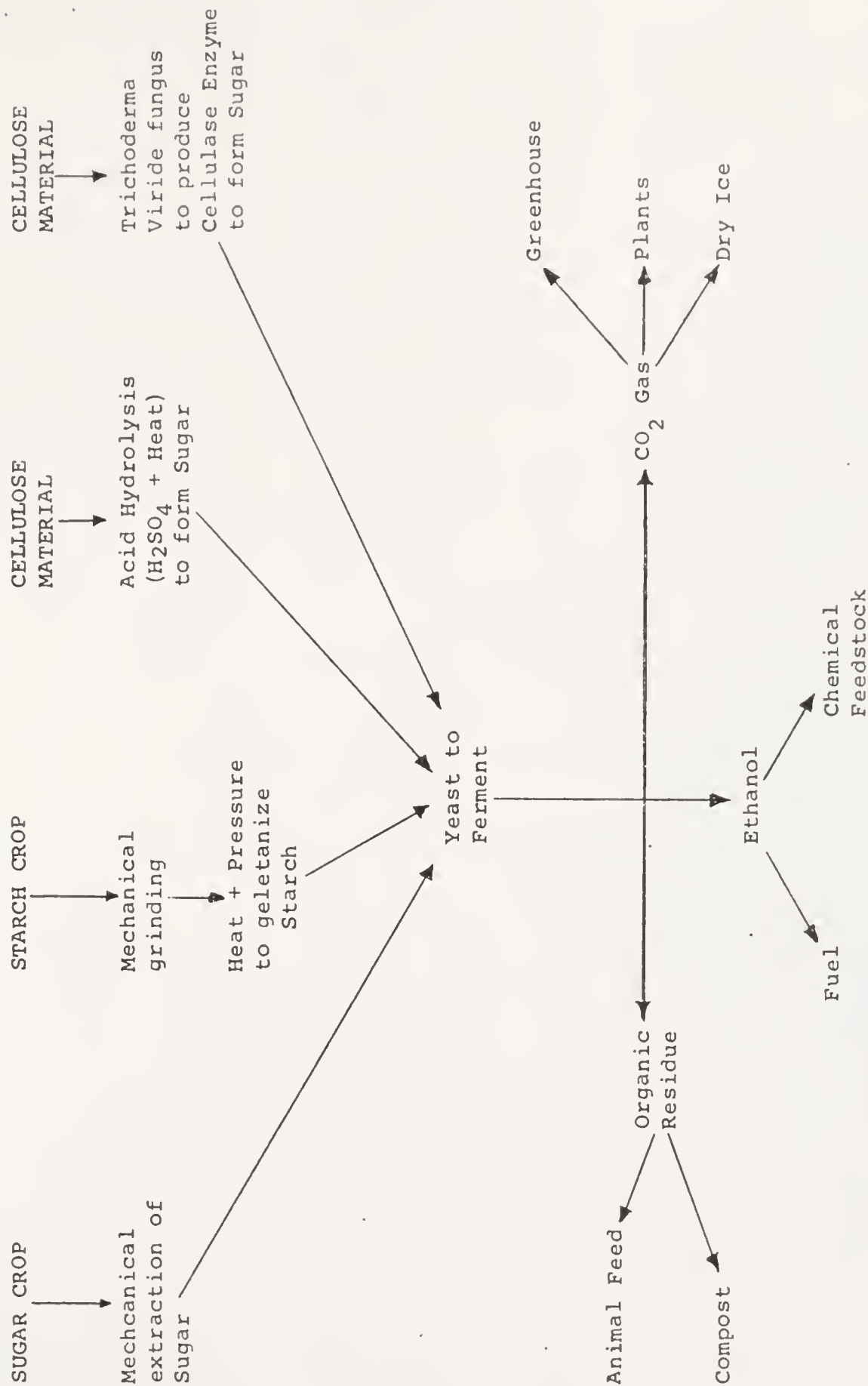


Table 9.10

Comparison of Commercial and Existing Prototype Units
for Alcohol Fermentation

Name, company or process	Primary Resource Used	Maximum Daily Loading	Energy and/or By-Products	Process Efficiency*	Reference
The Madison Wood Sugar Process (acid hydrolysis)	Wood, other cellulose mat- erial could be used	80 tons prototype built and operated in 1957	hexose sugar for further fermenta- tion and an organic residue	50% conversion to sugar 25% overall** to ethanol	Meller (1969) Dugas (1973)
1942 indus- trial pro- cess using corn as feedstock	corn or other starch/grain source	n/a	ethanol (95%) and organic residue	50%**	Dugas (1973)

* Process Efficiency = $\frac{\text{BTU value of energy output}}{\text{BTU value per pound of dry matter of the Resource} + \text{other process energy inputs}}$

**Does not give a full energy balance.

9.2.3 Photochemical

9.2.3.1 Hydrogen through Photolysis

Hydrogen production by photolysis occurs in some green plants and bacteria. Molecular hydrogen can be isolated by modifying the end results of the photochemical process in which active hydrogen reduces carbon dioxide to produce sugar. This is done by limiting carbon dioxide and lowering the oxygen level to induce the plant to convert the light energy directly into hydrogen (Calvin, 1976).

In 1974, the Boeing Company did a literature search to determine if a commercial application of this process could be developed. The investigator's summary stated that the process was in an early development stage and that "development of the process to the point of producing commercially useful quantities of hydrogen will require extensive development..." Other than to mention it as a possible future development, any assessment of this as a possible resource for Montana seems beyond the scope of this work.

9.3 Resources and Cost Assessment

The resources available for recovery from existing biomass in Montana are evaluated for the following categories:

Wood

Agriculture

Animal manures, crop residues

Urban

Solid organic waste, sewage

To assess the amount of biomass available in Montana, it is necessary to know the location, concentration, and production of various resources. In addition to existing resources available for bio-conversion processes, there will be an evaluation of the technical feasibility for both terrestrial and fresh water energy plantation as future biomass sources.

Resource recovery has been focused on the general areas: human waste (sewage and urban solid waste), food related waste (agriculture, animal manure), and the wood industry (harvesting and processing).

TABLE 9.11

SUMMARY OF BIOMASS RESOURCES FOR MONTANA -- BTU/YR

RESOURCE	TOTAL AVAILABLE ENERGY: BTU/YR		DIRECT COMB. TO STEAM: BTU/YR		METHANOL BY PYROLYSIS: BTU/YR		METHANE BY FERM. BTU/YR*	
	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW
<u>WOOD</u>								
Plant Residue	8.1×10^{12}	8.1×10^{12}	6.9×10^{12}	6.9×10^{12}	5.1×10^{12}	5.1×10^{12}	--	--
Logging Residue	5.2×10^{12}	1.2×10^{12}	4.4×10^{12}	1.0×10^{12}	3.2×10^{12}	7.6×10^{11}	--	--
Dead Timber	1.8×10^{14}	4.2×10^{13}	1.5×10^{14}	3.6×10^{14}	1.1×10^{14}	2.6×10^{13}	--	--
<u>AGRICULTURE</u>								
Animal Manure		2.7×10^{12}		1.3×10^{12}		1.6×10^{12} **	9.7×10^{11}	
Crop Residue	6.6×10^{13}	3.9×10^{13}	5.6×10^{13}	3.3×10^{13}	4.1×10^{13}	2.5×10^{13}	2.3×10^{13}	1.4×10^{13}
<u>HUMAN WASTE</u>								
Municipal Sewage	1.7×10^{10}	8.5×10^9	1.5×10^{10}	7.2×10^9	1.1×10^{10}	5.4×10^9	6.1×10^9	3.1×10^9
Solid Waste	2.7×10^{12}	1.8×10^{12}	2.3×10^{12}	1.5×10^{12}	1.7×10^{12}	1.1×10^{12}	9.7×10^{11}	6.5×10^{11}

*BTU/YR INCLUDES SECONDARY OUTPUT OF FERTILIZER IN BTU/YR SAVED

**HYDROGENATION PROCESS



FOREST TYPES

Figure 9.22

SOURCE:

U.S.D.A., Forest Service, Forest Resources of Montana, 1952

9.3.1 Wood Resource Assessment

Wood is one of Montana's abundant renewable resources. The largest portion of this reserve is located west of the continental divide (see Figure 9.22). The harvesting of this woody biomass for wood, paper and heat produces wood "waste" that is left in the forest or near lumber and plywood mills. Setzler (1971) has given the cubic feet of lumber and plywood residues in Montana that are left after all of the usable portions have been removed (Table 9.12). The location of this resource is indicated by the map 9.23 indicating lumber production.

Owen (1975) stated that only 10 to 20 percent of the total wood waste from logging operations lies within reach of access roads. An improved comprehensive forest management program would include the collection of this excess residue and the salvaging of dead but sound wood, "and generally cleaning and clearing the forests," (Shafizadeh, 1976). An excessive collection of forest residue might degrade the soil. Moslemi (1975) states that this is a pertinent question which will require research. Moslemi states, however, that cleaning up the forests will significantly reduce the fire hazard and, thereby, improve the productivity of the forest lands.

New harvesting techniques, such as whole tree harvesting and chipping systems, produce much less debris while converting the trees and residue into a convenient form. Frickson (1975) reports that by using these techniques, it is possible to recover up to 85 percent of the residue from logging operations and 44 percent from fire, disease, and insect damage timber (see Table 9.12).

The Georgia Tech mobile pyrolysis concept (Tatom, 1975) would be very applicable to the reduction of accumulated wood wastes found near lumber processing operations. Such a unit can be moved to areas of high biomass concentrations such as lumber industries. The low BTU gas is used to dry the incoming wood for better combustion. The resulting "char" can be burned with coal for energy production. When the wood waste pile is sufficiently reduced, the mobile pyrolysis unit can be packed up and moved to the next site.

LUMBER PRODUCTION

Figure 9.23

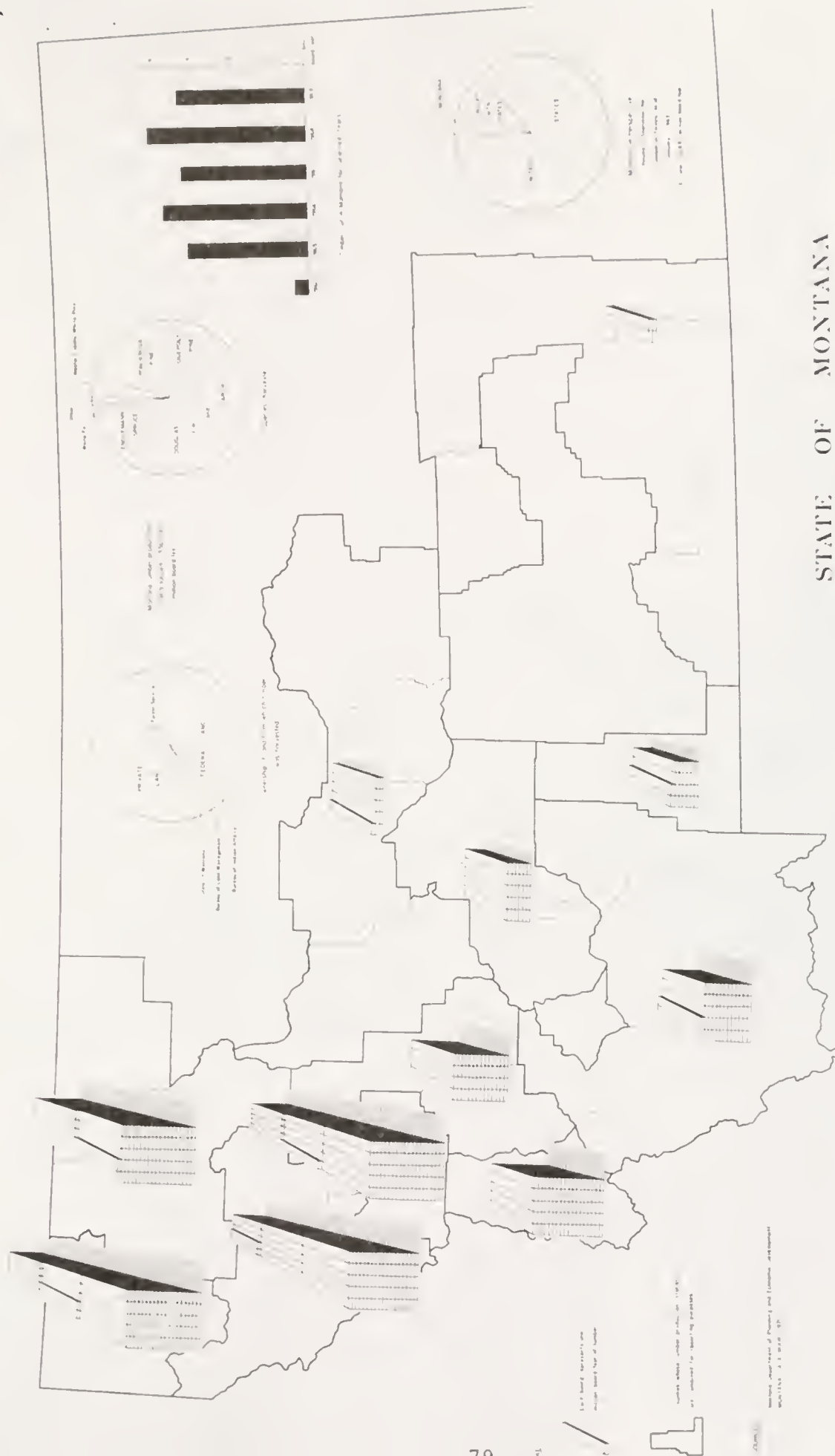


Table 9.12

Montana Wood Resources

Total cubic feet	% of possible recovery	cu.ft. available	pounds @ 25 lbs cu.ft.	dry weight - lbs @ 30% moisture	heat value BTU's @8000 BTU/dry lb.
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Unused plant residues from lumber, veneer and plywood industries 1969 (Seltzer, 1971)

Bark 27.3×10^6		27.3×10^6	6.8×10^8	4.8×10^8	3.8×10^{12}
Coarse 8.2×10^6		8.2×10^6	$2. \times 10^8$	1.4×10^8	1.1×10^{12}
Fine 22.8×10^6		22.8×10^6	5.7×10^8	4.0×10^8	3.2×10^{12}

BTU Plant
Subtotal

Logging Residues (Erickson, 1975)
1970 (Shafizadeh, 1976)

W. Mont 39.1×10^6	85%	3.3×10^7	8.3×10^8	5.8×10^8	4.6×10^{12}
E. Mont 4.9×10^6	85%	4.1×10^6	1×10^8	7.2×10^7	5.8×10^{11}
				Logging Subtotal	5.2×10^{12}

Salvageable dead timber

3.0×10^9	44%	1.3×10^9	3.3×10^{10}	2.3×10^{10}	1.8×10^{14}
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If only 20% (instead of 85%) of logging residues are recovered as Owen (1975) suggests, and only 10% of salvageable dead timber¹³ collected, then this would change the logging totals to:

W. Mont 39.1×10^6	20%	7.8×10^6	$2. \times 10^8$	1.4×10^8	BTU @ 8000 BTU/dry lb. 1.1×10^{12}
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E. Mont 4.9×10^6	20%	9.8×10^5	2.5×10^7	1.7×10^7	1.4×10^{11}
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Salv. Dead Timber
 3×10^9

	10%	$3. \times 10^8$	7.5×10^9	5.3×10^9	4.2×10^{13}
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4.3×10^{13}

Table 9.13
SUMMARY OF BIOMASS ENERGY OPTIONS FOR MONTANA

Resource: Wood Residue = 1.93×10^{14} (high est.) - 5.13×10^{13} (low est.)

Conversion Process	Primary Output in BTU/lb Input	Primary* Process Efficiency	Secondary Output in BTU/lb Input	Overall** Efficiency Including By-product	\$ Cost per mmBTU	Capital Cost in \$ per mmBTU/yr	Comments Context
Direct Buring	Steam @ 6800	85%	Ash*** N.A.	85%	Fuel \$0.05 Conv. 2.76 Total 2.81	\$22.08	Sawdust, shavings & hogged fuel at Plum Creek lumber in Colum Falls, Mt., 98% process steam
Direct Burning	Electricity @ 2400	30%	Ash*** N.A.	30%	Fuel \$0.65 Conv. 3.84 Total 4.49	\$30.72	"Using 1000 MW, moderate high temperature, high pressure station..." (Alich & Inman, 1973)
Pyrolysis	Methanol @ 5040	63%	Ash*** N.A.	63%	Fuel \$0.65 Conv. 2.73 Total 3.38	\$30.76	Fuel cost from Alich & Inman (1973) conversion cost based on \$10,500 year cost producing 40,000,000 gallons/yr. (Sheehan, 1974)
Pyrolysis	Char oil & Low BTU gas @ 5440	68%	Ash*** N.A.	68%	Fuel \$0.65 Conv. 1.31 Total 1.96	\$10.48	Fuel cost est. (Alich & Inman, 1973) Conversion based on \$20/ton coal breakeven (Tatom

* Process Efficiency = $\frac{\text{BTU value per pound (dry weight basis) of fuel or energy output}}{\text{BTU value per pound dry matter of the resource plus other process energy inputs}}$

** Overall Efficiency = $\frac{\text{BTU value per pound of fuel or energy output plus energy value of by-products (e.g., fertilizer)}}{\text{BTU value per pound dry matter of the resource plus other process energy inputs}}$

***Residue of ash at $\approx 12\%$ which can be returned to the soil. The economic value nor the energy value is significant and consequently not applicable (N.A.)

9.3.2 ANIMAL MANURE RESOURCE ASSESSMENT

Animal residues for Montana have been assessed using statistics from County Statistics for 1973 (United States Department of Agriculture, 1974). Only those animals "on feed" have been considered in this assessment.

Table 9.14

Production of Animal Manure in Montana

Animal	1,000 Head	Total Production* Dry Wt. Lbs./Year
Beef Cattle	122	2.9×10^8
Dairy Cattle	31	1.7×10^8
Hogs	179	0.6×10^8
Chickens	1,190	0.2×10^8
Total	1,522	5.4×10^8

* All estimates are based on total solids as determined by Hermanson, 1974.

A comparison of fuel values for different conversion processes has been made and these values are given in the Summary of Biomass Energy Options for Montana (See Table 9.15). Direct combustion yields 5,000 Btu/day/lb (Dugas, 1973). However, since fresh manure contains 80% moisture, some heat energy (1,200 Btu/lb) must be used to evaporate the water in the manure before it can be efficiently combusted. If each cattle unit produces 60 lbs/day, then 12 lbs will be combustible solids (60,000 Btu) and 48 lbs will be water requiring 57,600 Btu to evaporate. The net 2,400 Btu/lb has been used to arrive at the energy value of manure for direct combustion.

Estimates of bio-gas production from the anaerobic digestion of cow manure used the following data:

- 1) bio-gas production of 42 cubic feet per cattle unit per day (Tainganides, et al, 1963);

- 2) Heat value of bio-gas is 600 Btu/cu.ft. (60% methane);
- 3) 50% of gross bio-gas production is used to maintain digestion temperature (95° F) and operate system (pumps, etc.).

Using this criteria, 1,800 Btu/lb has been used to determine the energy value of the manure for the methane fermentation process.

The figure given for hydrogenation is taken from the literature (Kash, et al, 1975). Assuming that all manure from animals on feed is collectible and usable, the following resource assessments were made:

Total (5.4×10^8) 5,000 Btu/lb = 2.7×10^{12} Btu

Methane (5.4×10^8) 1,800 Btu/lb = 9.7×10^{11} Btu

Direct Combustion (5.4×10^8) 2,400 Btu/lb = 1.3×10^{12} Btu

Hydrogenation (5.4×10^8) 2,950 Btu/lb = 1.6×10^{12} Btu



STATE OF MONTANA

CATTLE, SHEEP & HOGS

As A Percent Of All Livestock

Figure 9.24

Figure 9.25

Feedlots and Cattle on Feed by Counties



Source: Montana Agriculture
Statistics (1974)

Table 9.15
SUMMARY OF BIOMASS ENERGY OPTIONS FOR MONTANA

Resource: Animal Manure = 5.5×10^{11} BTU/yr (high) to 2.1×10^{11} BTU/yr (low).

Conversion Process	Primary Output in BTU/lb Input	Primary* Process Efficiency	Secondary Output in BTU/lb Input	Overall** Efficiency Including By-product	\$ Cost per mmBTU	Capital Cost in \$ per mmBTU/yr	Comments Context
Methane Fermentation	Biogas @ 1800	36%	Fertilizer 100	38%	\$2.54	\$20.32	Based on 60,000 head confined feedlot computer model
Direct Burning	Heat @ 2400	48%	Ash N.A.	48%	N.A.		Fumes from burning cow dung--bad environmental impacts are reported (Singh, 1973)
Hydrogenation	Oil @ 2950	59%	Ash N.A.	59%	\$3.21	\$25.68	(Kash, et al, 1975) Based on 2000 ton day plant using 1973 cost data of 11.00/ton

* Process Efficiency = $\frac{\text{BTU value per pound (dry weight basis) of fuel or energy output}}{\text{BTU value per pound dry matter of the resource plus other process energy inputs}}$

BTU value per pound of fuel or energy output plus energy value of by-products (e.g., fertilizer)
 **Overall Efficiency = $\frac{\text{BTU value per pound dry matter of the resource plus other process energy inputs}}{\text{BTU value per pound dry matter of the resource plus other process energy inputs}}$

9.3.3 CROP RESIDUE ENERGY

Montana has about 7 million acres on which farmers are producing wheat (2 million acres) and barley (5 million acres) See maps 9.26 and 9.27. Harvesting these resources usually leaves a sizable quantity of residue that can be collected and used for fuel. Downing (1975) has assumed that the available crop residue in western Canada, under low rainfall areas, is 3/4 ton per acre per year "where a high percentage of the residue is needed to maintain humus in the soil and for mulch tillage purposes for wind erosion control." This amount nearly doubles in eastern Canada. Therefore, since about 1/3 is not recoverable, the 3/4 ton per acre/year is a removal of about 1/3 of the total available crop residue. Downing also states that the "energy value for crop residue such as straw is given as 12.5 million BTU per ton."

Once the economics and energetics of collection and use of these dispersed resources are established, almost all of the 3/4 ton/acre/year could be collected. However, current costs and collection technologies bring this amount down to only 30% of the available residue (Crentz, 1973). This would reduce the .75 tons/acre/year down to .45 tons/acre/year. Therefore, to make a comparison, both high and low estimates of crop residue are given below.

$7 \times 10^6 \text{ acres} \times 0.75 \text{ tons/acre} \times 12.5 \times 10^6 \text{ BTU/ton} = 6.6 \times 10^{13} \text{ BTU}$
at 20% collection this would be $1.3 \times 10^{13} \text{ BTU}$.



STATE OF MONTANA

HAY HARVESTED

As A Percent Of Cropland Harvested

Figure 9.26

STATE OF MONTANA HARVESTED WINTER WHEAT, SPRING WHEAT, AND BARLEY

As A Percent Of Cropland Harvested

Figure 9.27

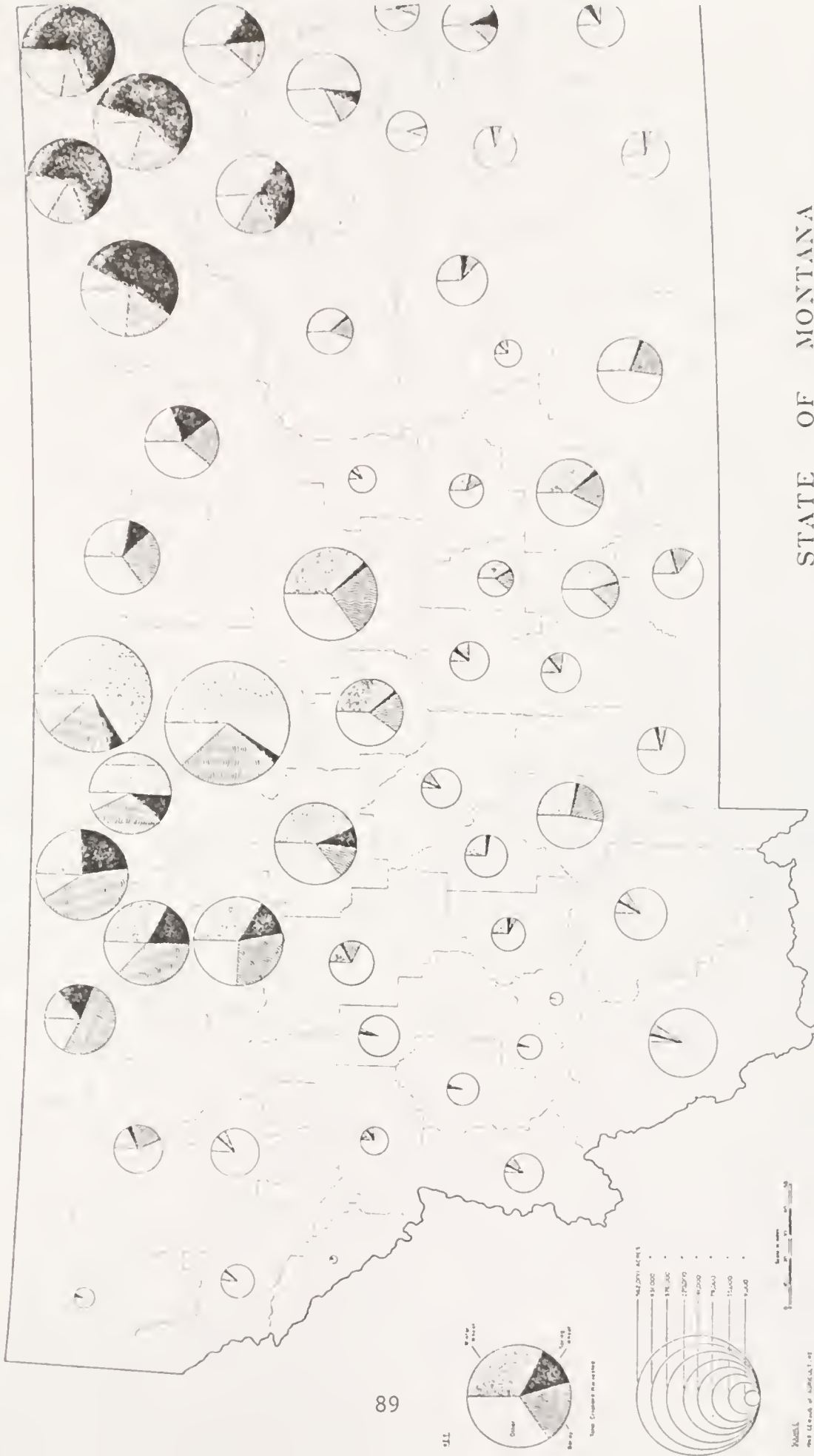


Table 9.16
SUMMARY OF BIOMASS ENERGY OPTIONS FOR MONTANA

Resource: Crop residue = 6.6×10^{13} BTU/yr (high) or 3.9×10^{13} BTU/yr (low)							
Conversion Process	Primary Output in BTU/lb Input	Primary* Process Efficiency	Secondary Output in BTU/lb Input	Overall** Efficiency Including By-product	\$ Cost per mmBTU	Capital Cost in \$ per mmBTU/yr	Comments Context
Direct Burning	Steam @ 5300	85%	Ash N.A.	85%	Fuel \$0.65 Conv. 2.76 Total 2.81	\$22.08	(Alich and Inman, 1974) Based on 1000 mw steam plant
Direct Burning	Electricity @ 1875	30%	Ash N.A.	30%	Fuel \$0.65 Conv. 3.84 Total 4.49	\$30.72	(Alich and Inman, 1974) Based on 1000 mw thermal electric plant
Pyrolysis	Methanol @ 4000	63%	Ash N. A.	63%	Fuel \$0.65 Conv. 2.73 Total 3.38	\$21.84	(Sheehan, 1974) Based on Union Carbide Plant operating on 340 ton day solid waste facility
Methane Fermentation	Biogas @ 2250	36%	Not significant at one pound	36%	Estimate Trans \$1.00 Conv. 2.50 Total 3.50	\$20.00	The fertilizer benefit is very significant. Cost mas volumes. Cost based on Alich and Inman (1973)

* Process Efficiency = $\frac{\text{BTU value per pound (dry weight basis) of fuel or energy output}}{\text{BTU value per pound dry matter of the resource plus other process energy inputs}}$

**Overall Efficiency = $\frac{\text{BTU value per pound of fuel or energy output plus energy values of by-products (e.g., fertilizer)}}{\text{BTU value per pound dry matter of the resource plus other process energy inputs}}$

9.3.4 MUNICIPAL SEWAGE

Humans produce .4 lbs. of excrement per day (Brown, 1974). Since this is 77% water by weight, its dry weight is .09 lbs. This represents a resource of 62,497 lbs. a day for the entire state. Thirty-eight percent of the population is served by septic tanks (Steiner, 1976); therefore, 23,748 lbs. a year are held in tanks throughout the state. The remaining 38,748 lbs. are carried via sewers to central treatment facilities. Secondary treatment plants have removal capacity of 85% (EPA, 1976). The wastes extracted in these plants represents 32,935 lbs. dry weight of human wastes. The sludge actually produced is considerably greater since it can be as much as 97% water.

Of the remaining 32,935 lbs. which is removed by central systems treatment, 32% (10,539 lbs.) is removed by settling lagoons. The remaining amount removed by mechanical systems is available for energy recovery (See Table 9.16).

Presently, eleven plants serving a population of 112,309 have anaerobic digestors. One of these plants, located in Great Falls (population 60,091), is discontinuing their digestion and going to heat treatment.

The major sludge disposal practice in the state is landfill, but some is used as fertilizer and soil conditioner on agricultural land (Missoula), nurseries (Bozeman), parklands (Great Falls), and cemeteries (Missoula).

Table 9.17
Municipal Sewage Sludge Generation for 18 Largest Towns in Montana

City	Population	Dry Weight of Waste in lbs/yr (at .09 lb/person/day)	Treatment Type	Anaerobic Digester
Billings	61,581	2,023,000 lbs	Activated sludge	
Great Falls	60,091	1,974,000	Primary (changing into activated sludge)	
Butte	35,000	1,150,000	Activated sludge	
Missoula	29,497	969,000	Activated sludge	Yes
Helena	22,730	746,000	Activated sludge	
Bozeman	18,670	613,000	Activated sludge	Yes
Havre	10,558	346,000	Activated sludge	
Kalispell	10,526	345,000	Activated bio-filter	
Malmstrom	10,000	328,000	Trickle filter	
Livingston	6,883	226,000	Primary	Yes
Lewiston	6,437	211,000	Primary	Yes
Laurel	4,454	146,000	Primary	Yes
Libby	3,286	108,000	Primary	
Columbia Falls	2,652	87,000		
Hamilton	2,499	82,000	Primary	Yes
Chinook	1,813	59,000	Trickle filter	
Eureka	1,195	39,000	Primary	
Harlem	1,094	35,000	Activated sludge	Yes
Subtotal for Systems with Anaerobic Digester	69,534	2,282,000		
GRAND TOTAL	288,966	9,487,000		

High value: 2.3×10^6 lbs/yr at 7300 BTU/lb = 1.7×10^{10} BTU

Low value: 2.3×10^6 lbs/yr at 3700 BTU/lb = 3.5×10^9 BTU

Table 9.18
SUMMARY OF BIOMASS ENERGY OPTIONS FOR MONTANA

Resource: Municipal Sewage = 1.7×10^{13} (high) to 8.5×10^{12} (low).

Conversion Process	Primary Output in BTU/lb Input	Primary* Process Efficiency	Secondary Output in BTU/lb Input	Overall** Efficiency Including By-product	\$ Cost per mmBTU	Capital Cost in \$ per mmBTU/yr	Comments Context
Direct Burning	Heat @ 4745	65%	Ash N.A.	65%	Conversion only \$2.76	\$22.08	Alich and Inman (1973)
Methane Fermentation	Biogas @ 2600	36%	Fertilizer @ 200	38%	\$2.09	\$16.72	Kispert (1974)

* Process Efficiency = $\frac{\text{BTU value per pound (dry weight basis) of fuel or energy output}}{\text{BTU value per pound dry matter of the resource plus other process energy inputs}}$

**Overall Efficiency = $\frac{\text{BTU value per pound of fuel or energy output plus energy value of by-products (e.g., fertilizer)}}{\text{BTU value per pound dry matter of the resource plus other process energy inputs}}$

9.3.5 MUNICIPAL SOLID WASTE:

Montana produced 590,000 tons of solid waste in 1975. Of this, 58.2% was combustible; the remainder consisted of such things as glass, metal, building debris, and sewage sludge. The average waste production rate was 4.92 pounds per person per day for urban areas, and 2.28 pounds per person per day for rural areas. The solid waste was 35.2% water and had a direct combustion value of 5039 BTU/lb. wet or 7541 BTU/lb. dry (Henningson, 1976).

Table 9.19
Solid Waste Generation in Montana

City	Population	lb/person/day solid waste	lb/year $\times 10^6$	Wet Combustible lb/year $\times 10^6$
Billings (metro)	84,300	6.26	192.6	112.1
Great Falls	66,043	4.51	108.7	63.3
Butte	35,000	6.07	77.5	45.1
Missoula	35,000	5.75	73.4	42.7
Bozeman (metro)	27,353	6.15	61.4	35.7
Helena	22,730	5.40	44.8	26.1
Havre	10,558	5.75	22.2	12.9
Kalispell	10,526	5.75	22.1	12.8
Miles City	9,500	5.96	20.7	12.0
TOTAL			623.4	362.7

Source: Heningson, et al, January 1976.

High value: 3.6×10^8 lbs/yr at 7541 BTU/lb = 2.7×10^{12} BTU/yr

Low value: 3.6×10^8 lbs/yr at 5039 BTU/lb = 1.8×10^{12} BTU/yr

Table 9.20

SUMMARY OF BIOMASS ENERGY OPTIONS FOR MONTANA

Resource: Municipal Solid Waste = 2.7×10^{12} BTU/yr (high) to 1.8×10^{12} BTU/yr (low)

Conversion Process	Primary Output in BTU/lb Input	Primary* Process Efficiency	Secondary Output in BTU/lb Input	Overall** Efficiency Including By-product	\$ Cost per mmBTU	Capital Cost in \$ per mmBTU/yr	Comments Context
Direct Burning	Steam @ 6400	85%	Ash N.A.	85%	\$2.56	\$20.48	Based on Wilmington Va., plant with budget credit capital cost of \$22.40/ton (Kas et al, 1975)
Pyrolysis	Methanol @ 4750	63%	Ash N.A.	63%	\$2.73	\$21.84	(Sheehan, 1974)
Methane Fermentation	Methane (biogas less CO ₂ & H ₂ S) 2800	37%	Fertilizer 200	40%	\$2.09	\$16.72	Based on 1000 ton per day model (Kispert, 1974)

* Process Efficiency = $\frac{\text{BTU value per pound (dry weight basis) of fuel or energy output}}{\text{BTU value per pound dry matter of the resource plus other process energy inputs}}$

**Overall Efficiency = $\frac{\text{BTU value per pound of fuel or energy output plus energy value of by-products (e.g., fertilizer)}}{\text{BTU value per pound dry matter of the resource plus other process energy inputs}}$

9.3.6 BIOMASS ENERGY PLANTATIONS

Many research institutes have been studying the feasibility of growing crops specifically for energy (Intertechnology Corporation, Stanford Research Institute, Battelle, Weyerhaeuser, Georgia Pacific, ERDA, etc.). An assessment of the potential for maximum production has focused attention on the southwest U.S. where yields ranging from 4 to 50 tons/acre/year can be attained (Greeley, 1976). Average yields range from 10 to 30 tons/acre/year. However, the availability of land and sun in the southwest is contradicted by the lack of water. Biomass energy plantations cannot economically compete with prime agricultural or forested land -- they can be used where there is at least 20 inches of rain per year and where the land is suitable for field machinery.

The most likely species of plants for use in this application are selected crop plants such as kenaf, sunflower, forage grasses, and certain tree species (Alich, 1974). Short season crops (i.e. 3 to 4 months for sunflowers) and multiple cropping annual species are practices that increase the yield per acre. Perennial plants are preferred to annuals because the planting and harvesting can take place throughout most of the year.

An optimum biomass energy plantation would cover an area of about 250 square miles and could fire a 1000 MW plant at a load factor of 80%. The power generation costs would be about 13.1 mills/kWh. (Alich, 1974). The Intertechnology Corporation, which has put a trademark on Energy Plantationtm, estimates that the cost of fuel produced by such a plantation would only be \$1.20/mm BTU. The Research Institute estimates the energy costs to run this concept

range from 5.5 to 15% of the energy produced - depending on irrigation energy requirements.

Wetland farming has also been seriously considered. Algae can be grown in shallow stabilization ponds in a sewage treatment facility as an oxidizing agent. Yields up to 70 dry tons/acre/year are attainable. United Technologies Corporation has proposed a water hyacinth energy farm. Water hyacinth removes nutrients from waste water. The proposed system would employ a 350 sq. mi. network of canals and cells. Each cell would have a receiver that would chop up the hyacinth into a slurry, and this would be digested to produce methane at a cost of about \$3.00/MM BTU (Greeley, 1976) .

The economic and practical feasibility of biomass energy plantations has not yet been demonstrated. Small scale plantations (say 50 sq. mi.) and moderate sun and rain areas have not been seriously considered. A thorough resource map of Montana should indicate the land areas suitable for these plantations as part of a comprehensive resource evaluation plan.

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